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FREE-FIELD STAGNATION PRESSURE AND IMPULSE FROM A HIGH EXPLOSIVE DETONATION IN A MODEL UNDERGROUND STORAGE FACILITY

STEPHEN J. ZARDAS

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U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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13. ABSTRACT *(Maximum 200 words)*
Results are presented from high-explosive (PETN) model tests conducted to determine free-field stagnation pressures and impulses produced by simulated underground chamber/tunnel explosions. The model consisted of a 1:50 scale, smooth, chamber/tunnel configuration with a converging area change. Internal side-on pressures and external side-on and stagnation pressures were measured as a function of chamber-charge loading density and external test-bed type (i.e., sand or plywood). Results of the tests indicate that the ratio of stagnation pressure to side-on pressure is dependent on terrain at the tunnel exit.

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1. INTRODUCTION

1.1 Background. The Department of Defense Explosive Safety Board (DDESB) has a need for the characterization of airblast hazards for use in determining quantity-distance (Q-D) standards for ordnance. This research effort addresses the approximate Q-D standards to be applied when munitions, stored underground, explode. A previous effort by BRL[1] in this area characterized the external side-on blast pressures from such explosions. However, it was noted that external stagnation pressures along the tunnel axis may considerably exceed the side-on pressures due to the high velocity of the jet flow exiting the tunnel.

Also, small-scale, shock-tube tests[2] showed that external stagnation pressures could be much higher than comparable side-on pressures. These high stagnation pressures, if produced by accidental detonation of underground storage facilities, could result in Q-D standards that are less than required.

1.2 Objectives. The objective of this effort, sponsored by DDESB, is to conduct scale-model tunnel tests to determine stagnation pressures relative to side-on pressures in the free field.

2. TEST PROCEDURES

A smooth-walled steel pipe chamber/tunnel model of 1:50 scale was operated with detonating cord as described in the following sections.

2.1 Test model. The test model used is shown in Figure 1. Pressure transducers were mounted in the chamber wall to record the reflected and quasi-static pressure in the chamber. A transducer was also placed near the exit end of the tunnel to record the side-on exit pressure. Transducers were also mounted in lead bricks along blast radials located at 0° and 45° from the tunnel exit to record both side-on and stagnation pressures. Figure 2 is a photograph of the model. Figure 3 shows the transducers mounted in ground baffles along the blast line. Ground distances for the transducer stations were chosen to record equal pressures on both blast lines at corresponding stations and are presented in Table 1. A photograph of the test site is shown in Figure 4. The detonating cord was cut in lengths, bundled, and placed in a cardboard tube, Figure 5, then centered in the chamber to give the desired loading density, as shown in Table 2.

This corresponds to a distributed storage of munitions in the chamber of an underground storage facility. Detonation was initiated at the closed-chamber end by a Type 2023 detonator. In tests 1 and 2 the charges were 0.0634 kg of PETN, and in tests 3, 4, and 5, the charge was 0.136 kg of PETN.

TABLE 1. Gage Locations.

	Distance from tunnel exit to gage, m	
Station	Shots 1 & 2	Shots 3, 4, & 5[a]
0-1	1.00	1.2
0-2	1.53	2.43
0-3	2.61	4.17
0-4	4.89	7.80
45-1	0.80	0.90
45-2	1.06	1.68
45-3	1.81	2.88
45-4	3.38	5.39

[a]45-degree blast line not used in shots 4 and 5.

Table 2. Shot Matrix.

Shot No.	Charge[a] weight, kg	Chamber-loading density, kg/m^3	Test base
1	0.0634	0.681	Sand
2	0.0634	0.681	Sand
3	0.136	1.46	Sand
4	0.136	1.46	Plywood
5	0.136	1.46	Plywood

[a] Explosive used was 0.0106 kg/m PETN detonating cord.

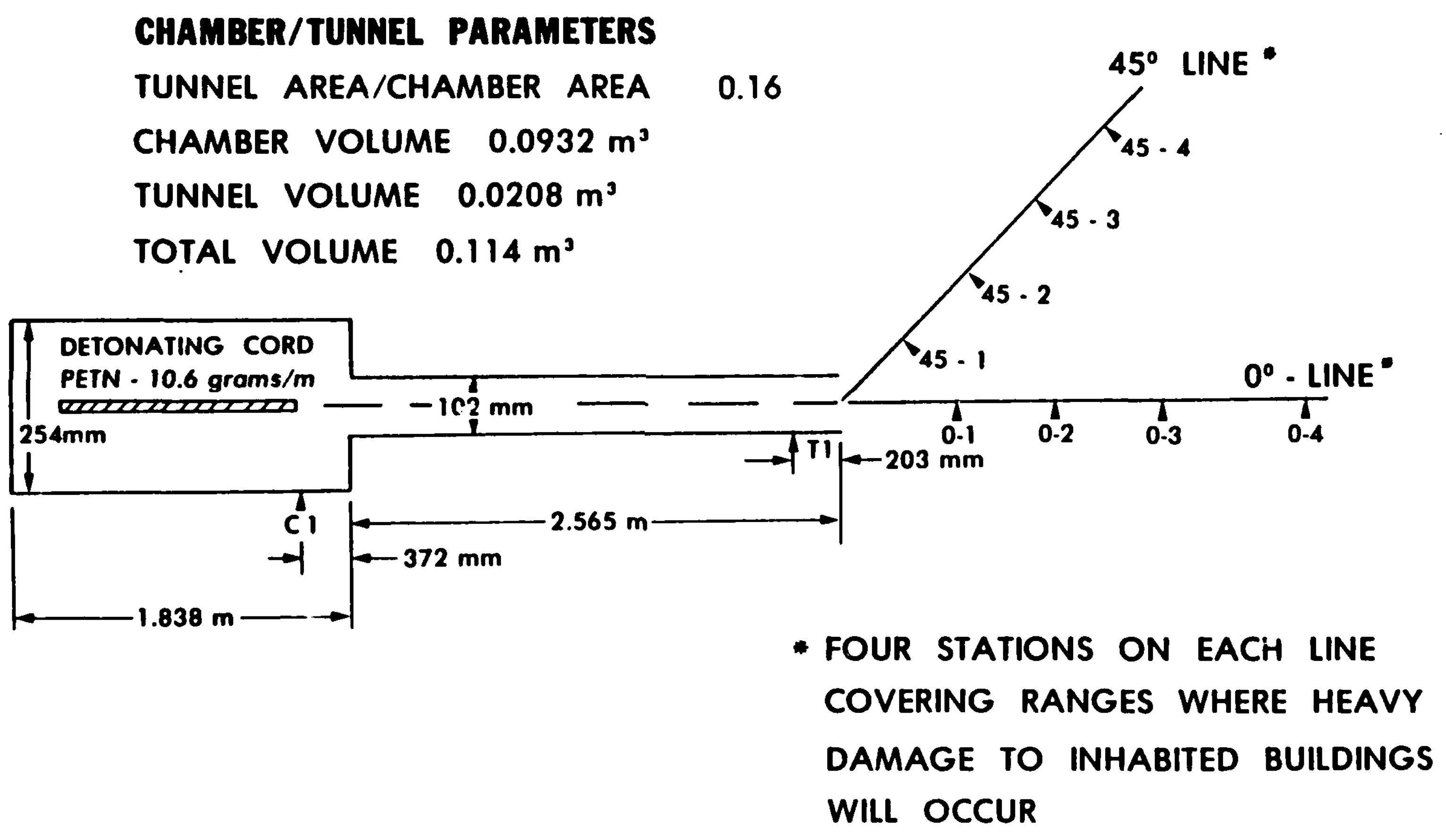

Figure 1. Chamber/tunnel configuration.

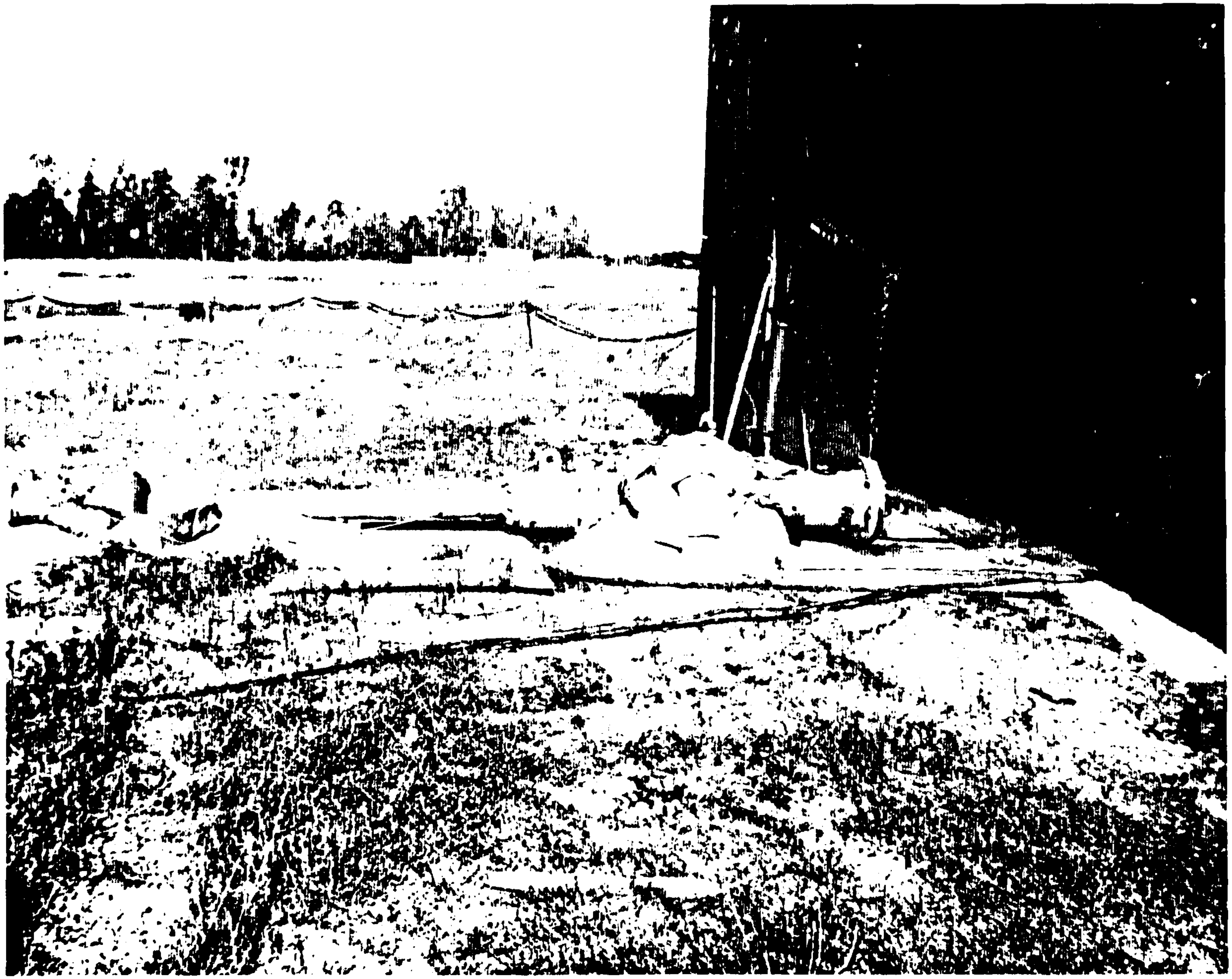

Figure 2. View of model chamber/tunnel.

Figure 3. Transducer mounted in ground baffle along a blast line.

Figure 4. View of test site showing 0- and 45-degree blast lines.

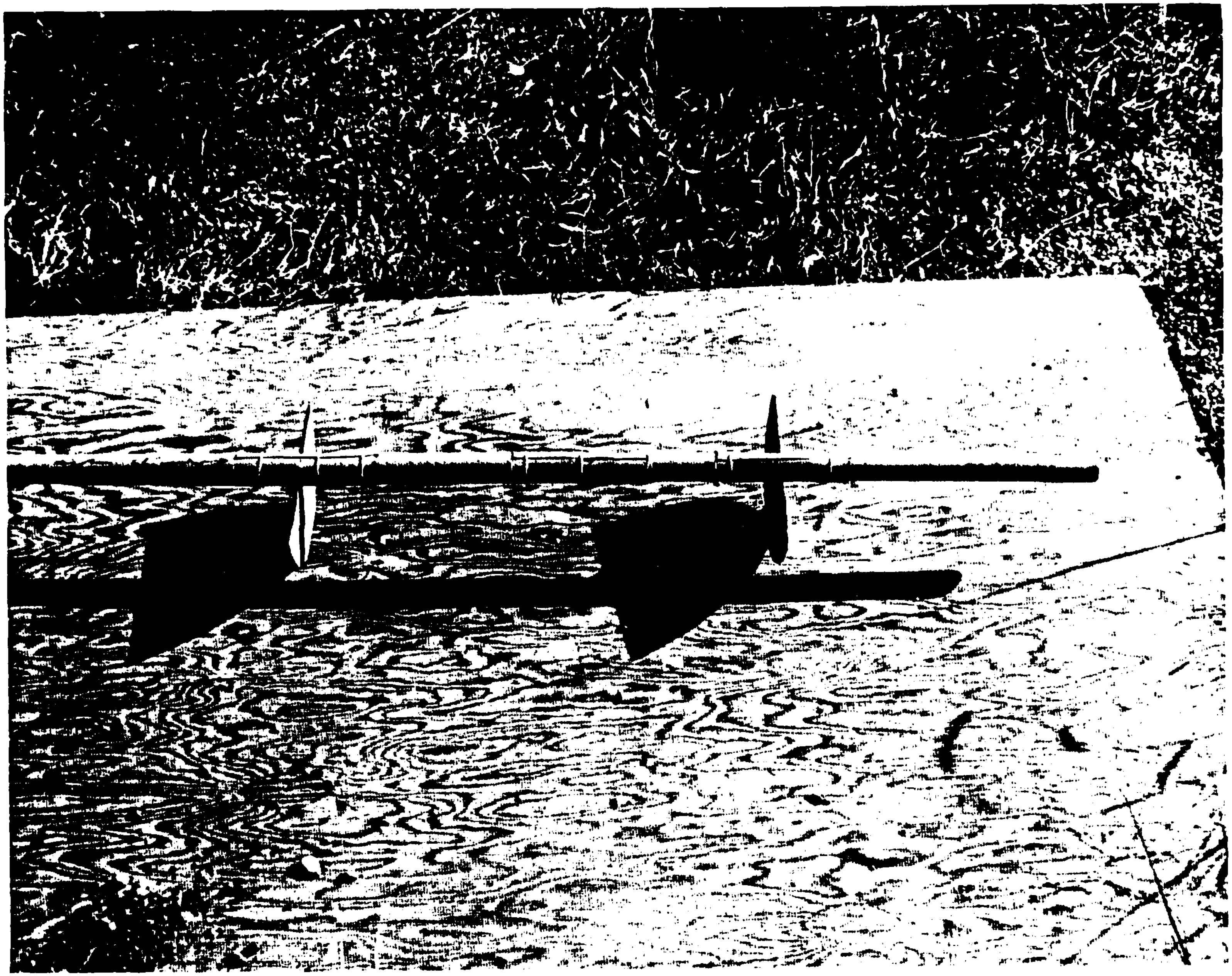

Figure 5. Centering device for detonating cord.

2.2 Instrumentation. The data acquisition-reduction system is shown in Figure 6.

3. RESULTS AND DISCUSSION

Figures 7 and 8 show post shot photographs of the disturbance of the sand test-bed surface from shots 2 and 3. There was some cratering near the exit and enough soot from the explosion to mark a path along the 0-degree line. The 45-degree line was essentially free from soot.

Appendix A presents pressure-time records from the chamber, tunnel, and each station of the blast lines. At station C-1, in the chamber, the records show that large blast reflections are produced at charge detonation. Then the pressure builds to some average quasi-static value and decays by exhausting into the tunnel and out the exit.

Blast wave propagation can be seen by comparing the records from each station on each blast line. Large, double-peaked waveforms are seen along the 0-degree line, but not on the 45-degree line. Whether or not the peaks catch up determines the maximum pressure at a given station.

The test model configuration was not varied during the shots; however, to maintain the predicted pressure levels of 68.95 kPa at station 1, 24.13 kPa at station 2, 11.72 kPa at station 3, and 5.00 kPa at station 4, the transducers were moved based on charge weight. Locations of chamber and tunnel transducers are shown in Figure 1.

Table 3 compares the peak side-on and stagnation pressures from the tests. In some instances multiple values of pressure were obtained, which are listed to show the extra peaks. Also, the experimental environment in the chamber was quite severe and few data were obtained there. Table 4 compares the external side-on and stagnation impulses.

Initially, it was expected, from the tests in the small-scale shock tube,[2] that the peak stagnation overpressures for shots 1 and 2 would be approximately 7 to 8 times the peak side-on overpressures at comparable gage locations along the 0-degree axis, and for shot 3, approximately 11 to 12 times greater. As shown in Table 3, stagnation overpressures were much lower than expected for shots 1 and 2 and even lower for shot 3.

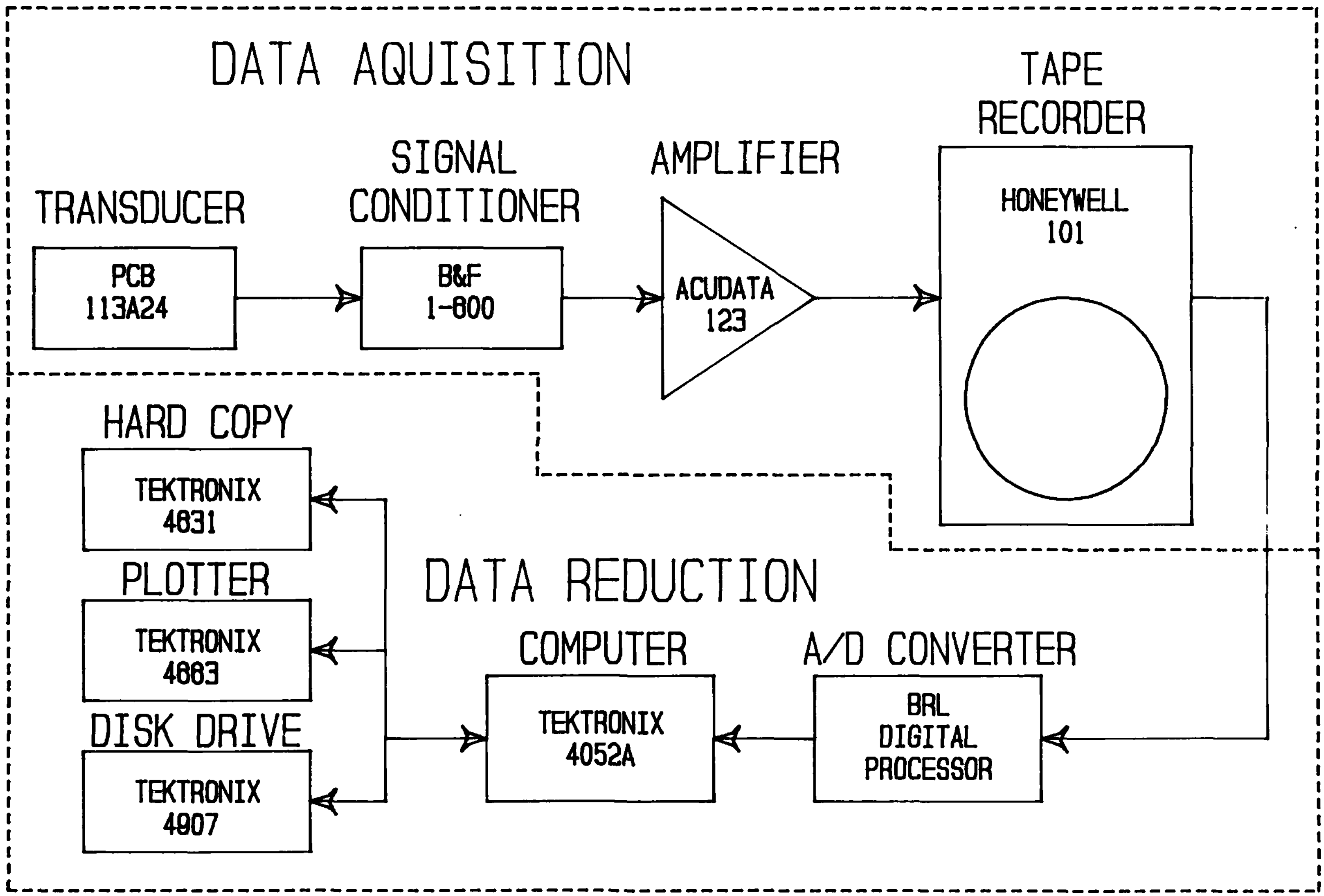

Figure 6. Schematic of data acquisition-reduction system.

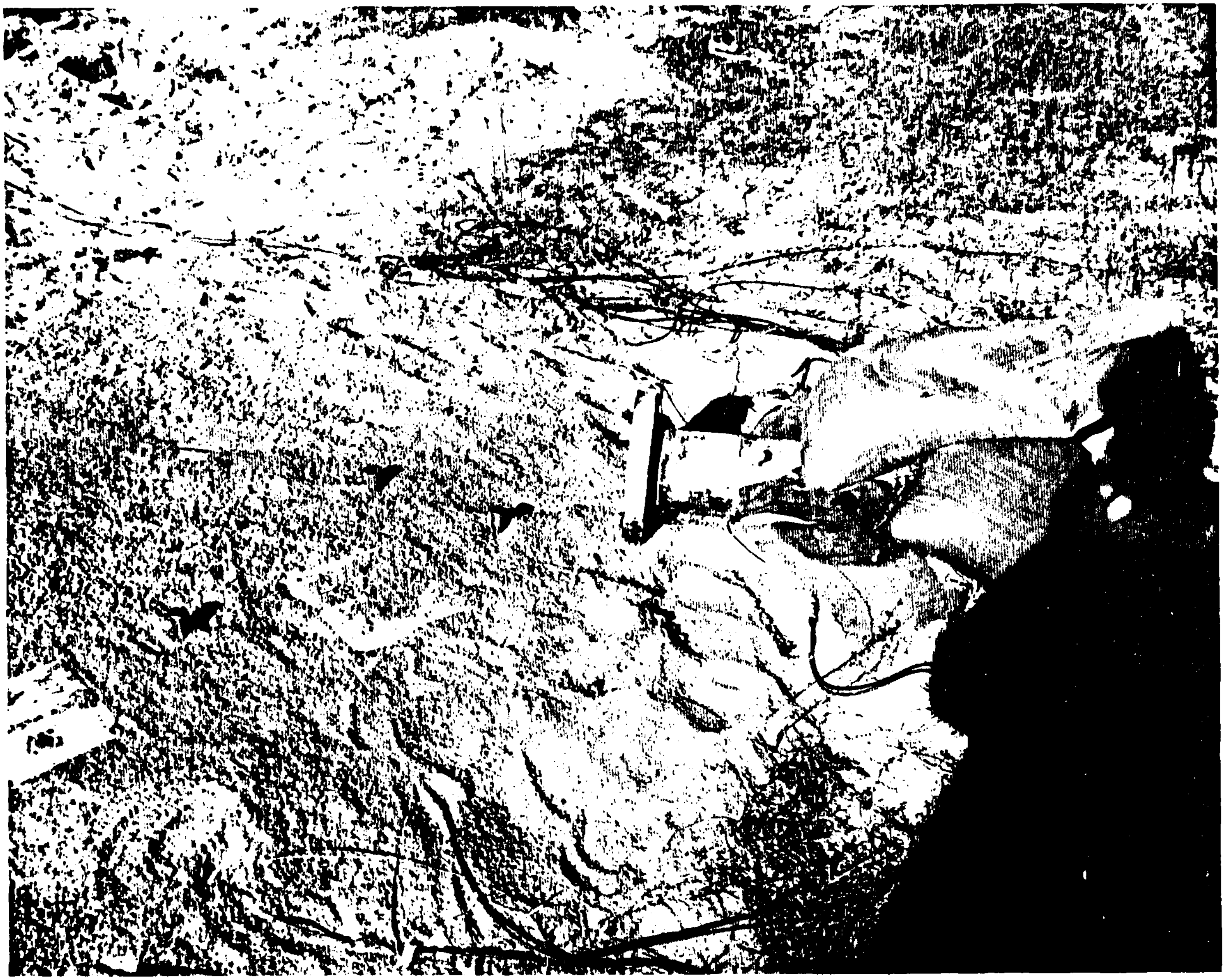

Figure 7. Sand disturbance at model exit, shot 2.

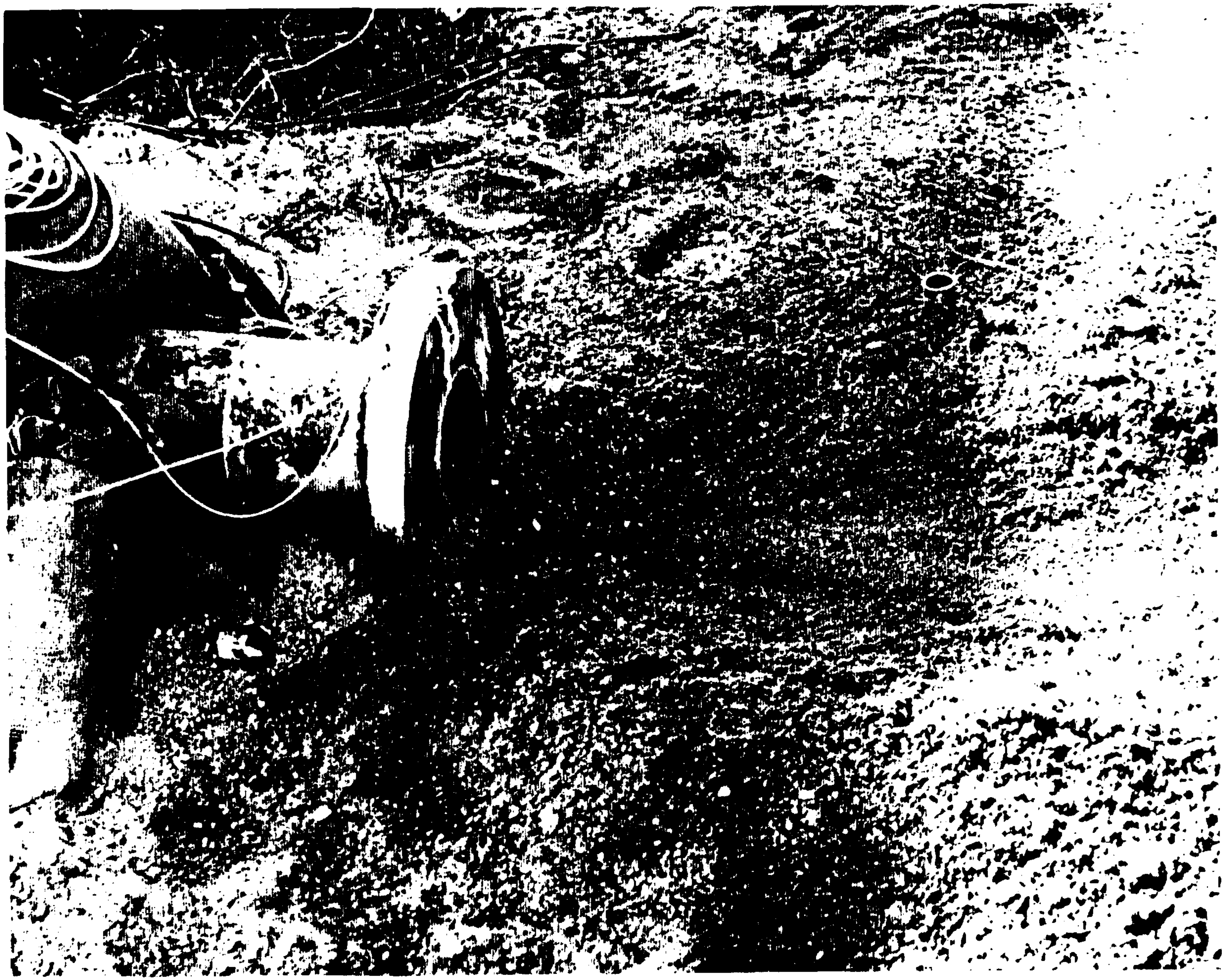

Figure 8. Sand disturbance at model exit, shot 3.

TABLE 3. Overpressure Comparison.

Station	Shot 1 Side-on (kPa)	Shot 1 Stagnation (kPa)	Shot 2 Side-on (kPa)	Shot 2 Stagnation (kPa)	Shot 3 Side-on (kPa)	Shot 3 Stagnation (kPa)	Shot 4 Side-on (kPa)	Shot 4 Stagnation (kPa)	Shot 5 Side-on (kPa)	Shot 5 Stagnation (kPa)
C-1	700	-	1,400	-	-	-	-	-	-	-
T-1	650	-	750	-	990	-	900	-	1,150	-
0-1	58	130/230	100	114/114	85	62	75	75/395	83	75/390
0-2	33	37	33	36	19/24	18	19/31	40/150	27/40	22/131
0-3	12	24	12	17	9.7	11	10/15	20/24	10/11	20/28
0-4	4.3	4	4.3	5.7	3.3	4.3	3.9	4.1	4.5	4.9
45-1	75	163	66	140	66	120	-- Not measured --			
45-2	33	44	31	47	27	33	-- Not measured --			
45-3	16	-	17	-	9.7	8.8	-- Not measured --			
45-4	5.8	11	5.5	11	3.3	5.0	-- Not measured --			

TABLE 4. Comparison of Side-on and Stagnation Impulses.

Impulse, kPa-msec

	Shot 1		Shot 2		Shot 3		Shot 4		Shot 5	
Station	Side-on	Stagnation	Side-on	Stagnation	Side-on	Stagnation	Side-on	Stagnation	Side-on	Stagnation
0-1	38	255	45	118	57	59	75	7,200	84	6,300
0-2	39	52	39	78	36	58	74	1,640	77	1,150
0-3	17	20	24	30	19	22	67	165	78	90
0-4	5.6	5.6	4.8	6.3	7.7	7.8	15	16	17	18
45-1	14	35	12	27	18	32	-- Not measured --			
45-2	11	13	11	13	17	22	-- Not measured --			
45-3	6.6	-	6.0	-	14	7.7	-- Not measured --			
45-4	3.8	4.5	3.0	3.9	7.3	8.5	-- Not measured --			

All possible variables and results of the tests were examined to determine the cause of this apparent anomaly. This examination indicated that the cause could be the type of material used in the model test bed. In the shock-tube tests plywood was used, whereas sand was used in the model tests. As shown in Figures 7 and 8, the sand at the exit of the model was somewhat disturbed in shots 1 and 2, and more noticeably disturbed in shot 3. From this, it was assumed that the shock wave disturbed the sand, which, in turn, interfered with the following high-speed jet flow from the tunnel.

A plywood sheet was placed, as shown in Figure 9, at the tunnel exit for shots 4 and 5. Also, 25.4-mm-diameter copper tubing, used in tests 1, 2, and 3 to deflect sand from the stagnation pick-up tubes, was not used in shots 4 and 5. As shown in Table 3, these measures proved fruitful: stagnation pressures from shots 4 and 5 were approximately four to five times the side-on pressures at stations 0-1 and 0-2. Also, stagnation pressure impulses were much greater than side-on values at stations 0-1, 0-2, and 0-3 for shots 4 and 5 as shown on Table 4 and Figures A-4 and A-5.

The free-field blast pressure can be predicted using a method described in Reference 1. In Figure 10, the solid line is the predicted value for the conditions of these tests and is plotted as the ratio of free-field blast pressure to tunnel-exit pressure ($\Delta P/P_w$) versus the ratio of radial distance to tunnel diameter (R/D_T). The measured data for the five shots are generally higher than predicted and are comparable with the results of Reference 1 which states that, under these conditions, a variation in free-field pressure of a factor of two may be expected.

4. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Results of tests to determine the free-field stagnation overpressures from explosions in a model storage chamber have been presented. Pressure-time records were obtained for stagnation and side-on overpressures on 0- and 45-degree radials as measured from the longitudinal axis of the tunnel, taken as 0 degrees. For shots 1 and 2, the measured stagnation pressures were somewhat lower than expected, and much lower for shot 3. Analysis indicated that the shock wave at the tunnel exit disturbed the sand test bed to the extent that the sand, in turn, interfered with the following high-speed flow. In shots 4 and 5 plywood was used at the tunnel exit and resultant stagnation overpressures were more nearly as expected.

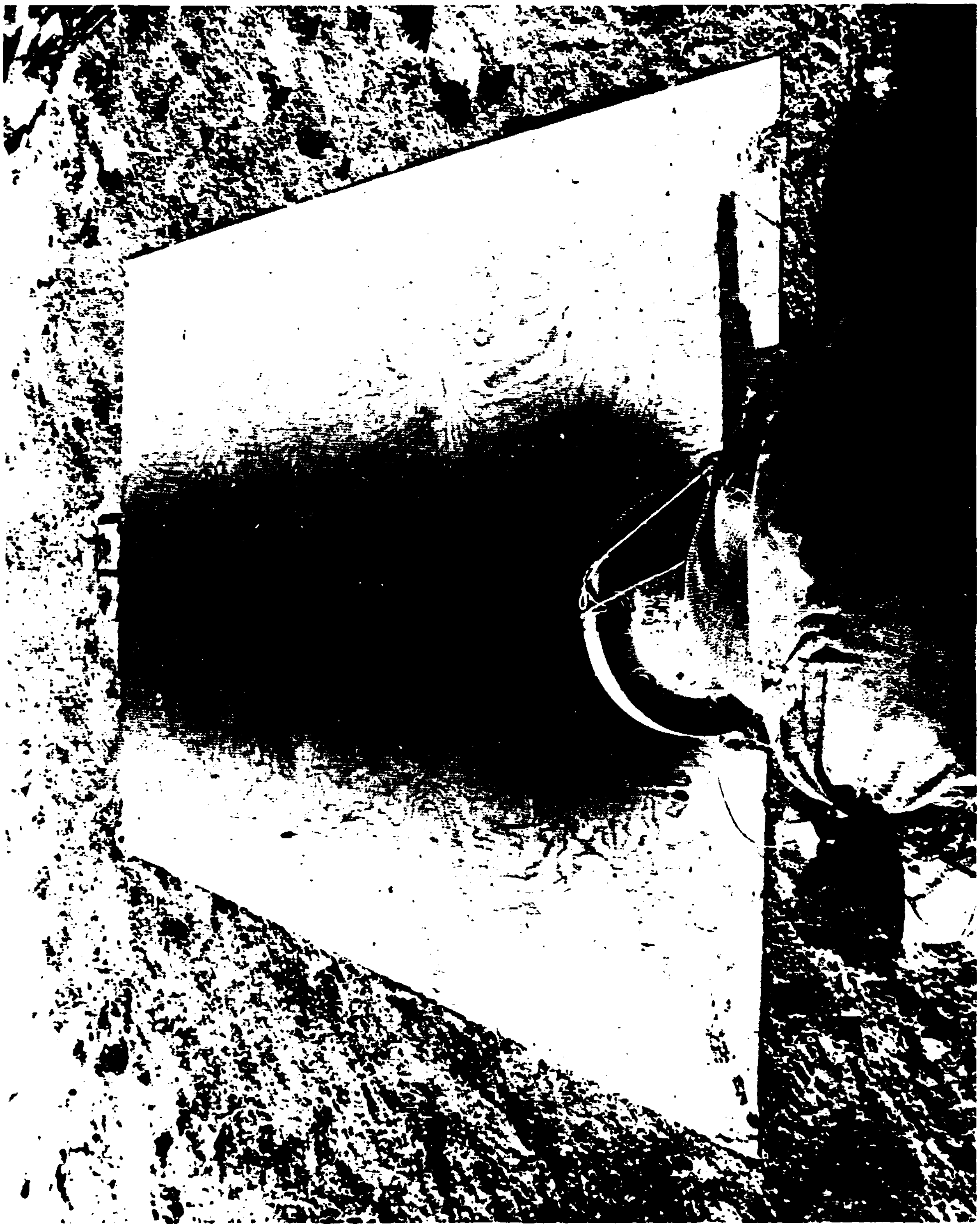

Figure 9. Post-shot photograph of shot 4.

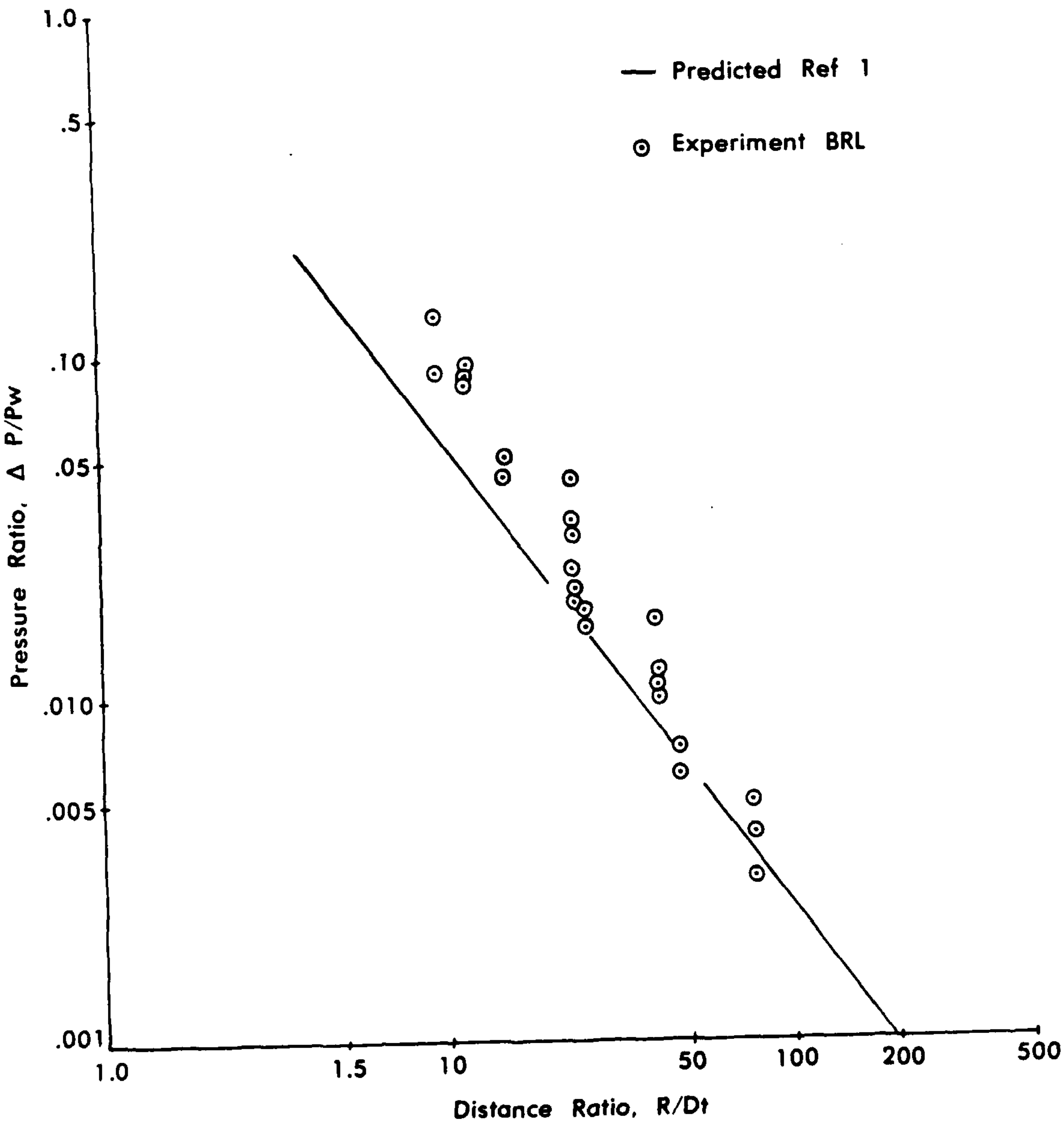

Figure 10. Pressure ratio versus distance ratio on 0-degree line outside tunnel.

From these minimum number of tests, it appears that the stagnation-to-side-on overpressure ratio is terrain dependent. However, the affect on stagnation pressure of removing the copper tubing sand deflectors is not known.

It is suggested that studies be continued to more adequately define the effect of sand and plywood and to determine the effects of different types of terrain features.

5. REFERENCES

1. Coulter, G. A., G. Bulmash, and C. N. Kingery. "Simulation Techniques for the Prediction of Blast from Underground Munitions Storage Facilities." BRL-MR-3659, U. S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, April 1988.

2. Kingery, C. N., and E. J. Gion. "Jet-Flow from Shock Tubes." BRL-TR-3015, U. S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1989.

APPENDIX A:

PRESSURE-TIME AND IMPULSE-TIME RECORDS

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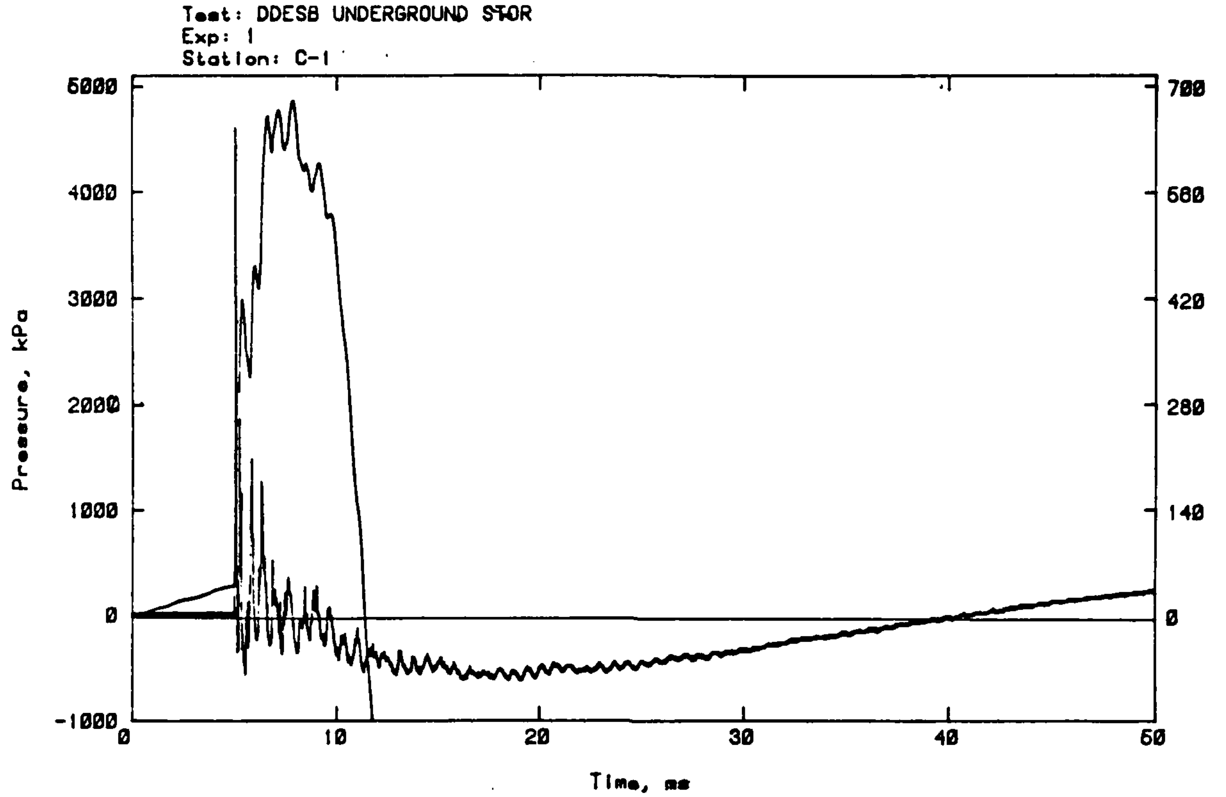


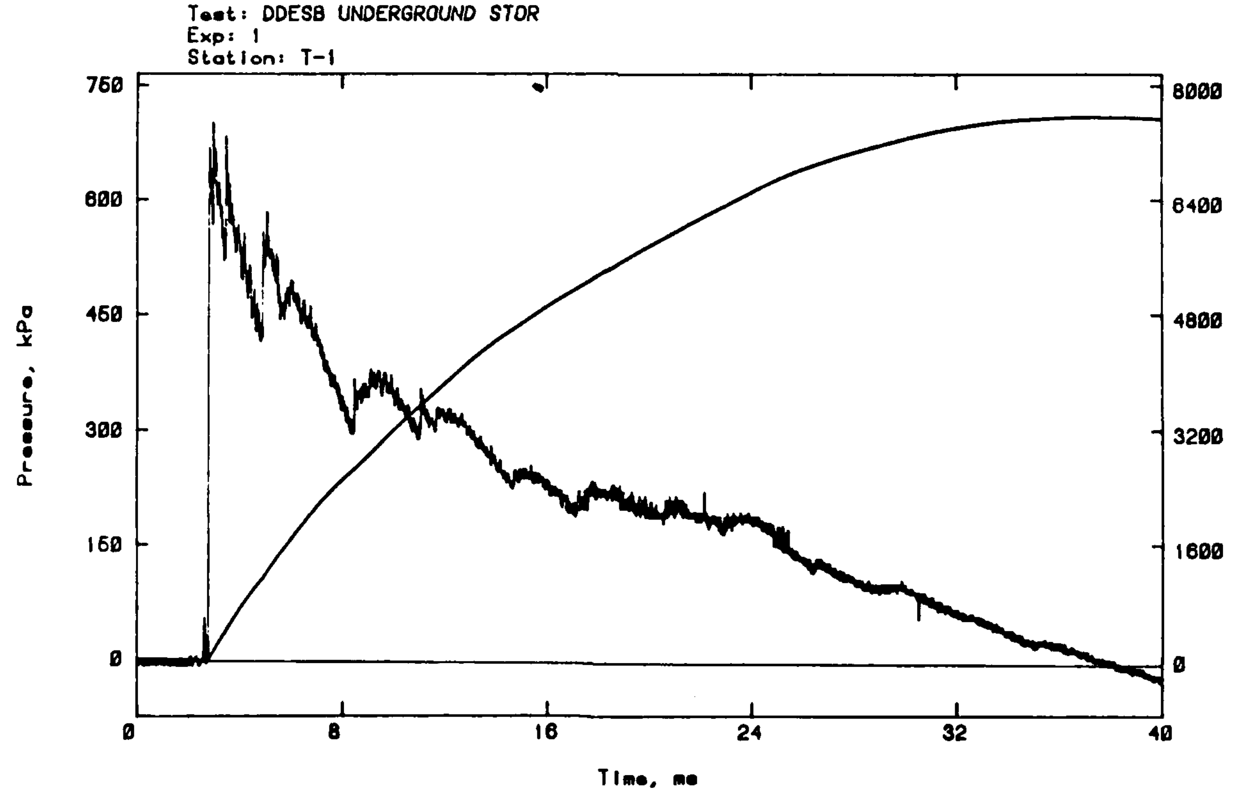
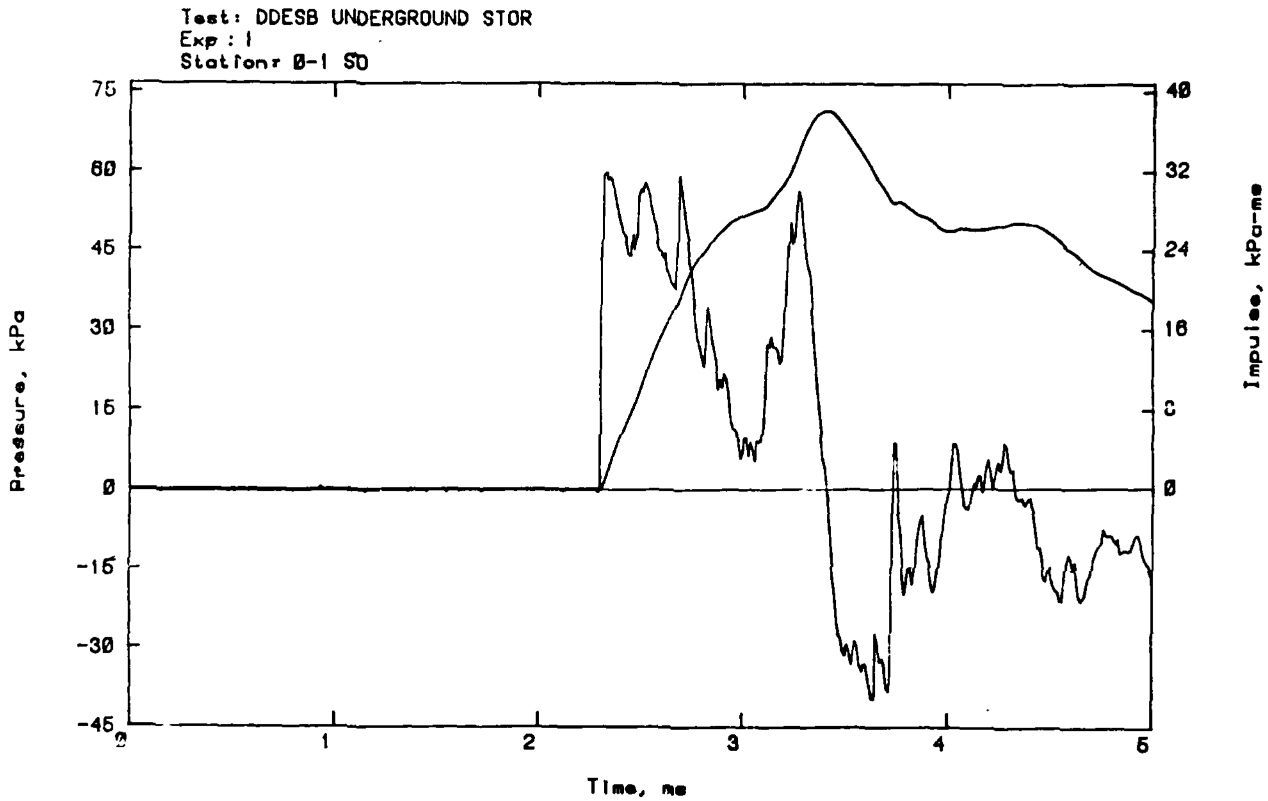
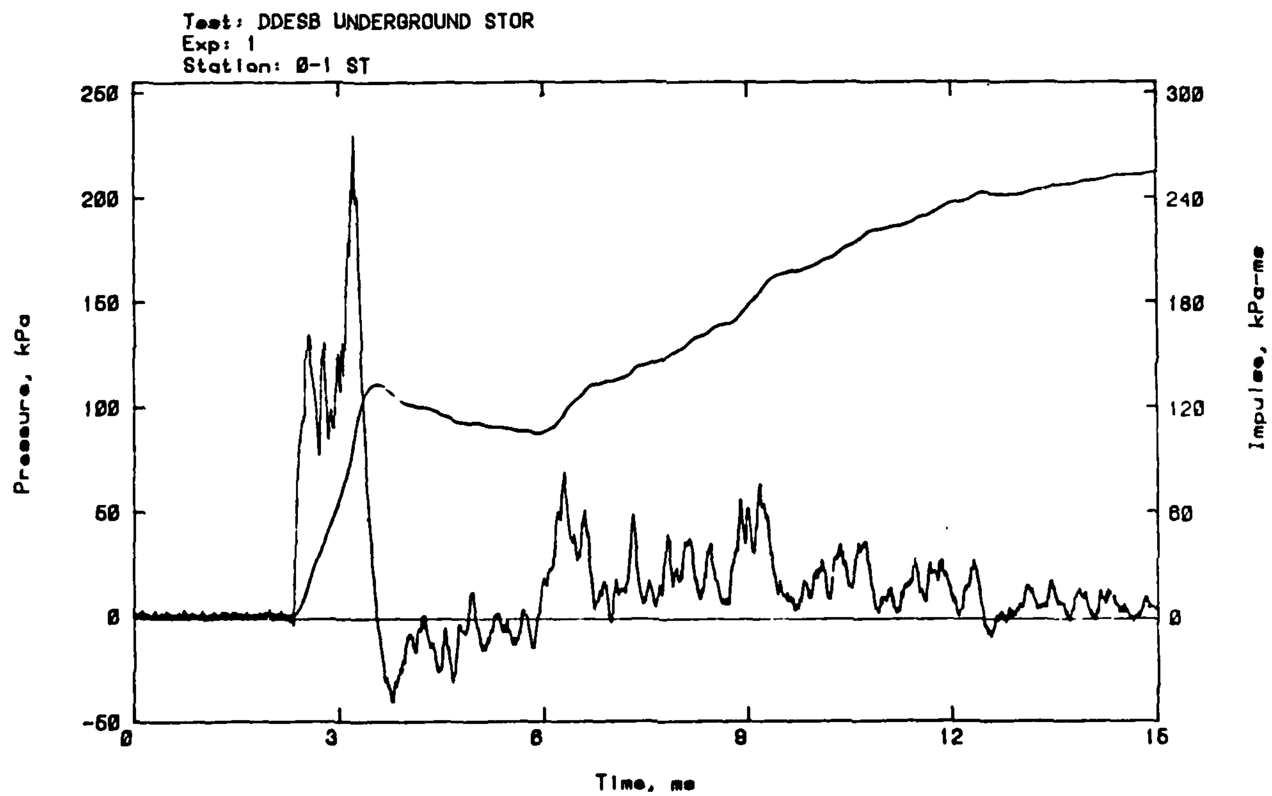


Figure A-1. Shot 1, chamber-loading density 0.681 kg/m^3, sand base.





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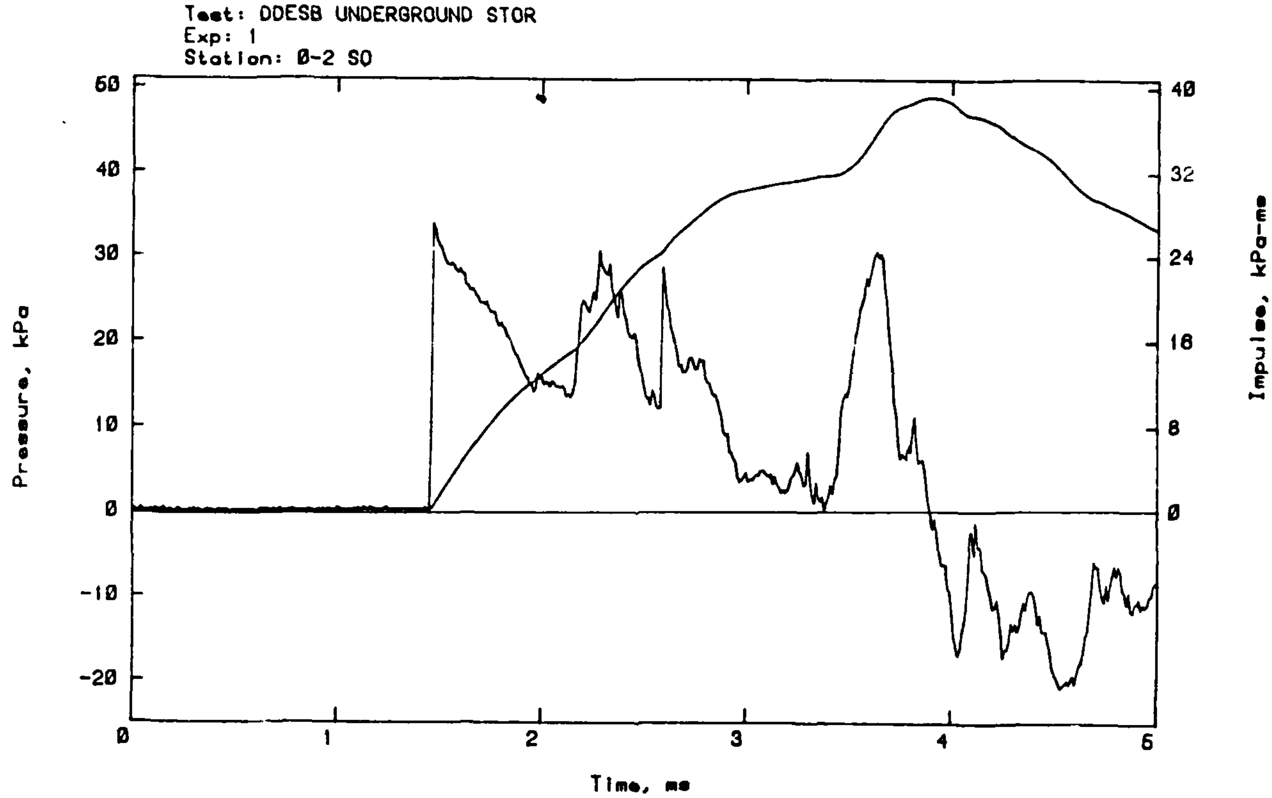


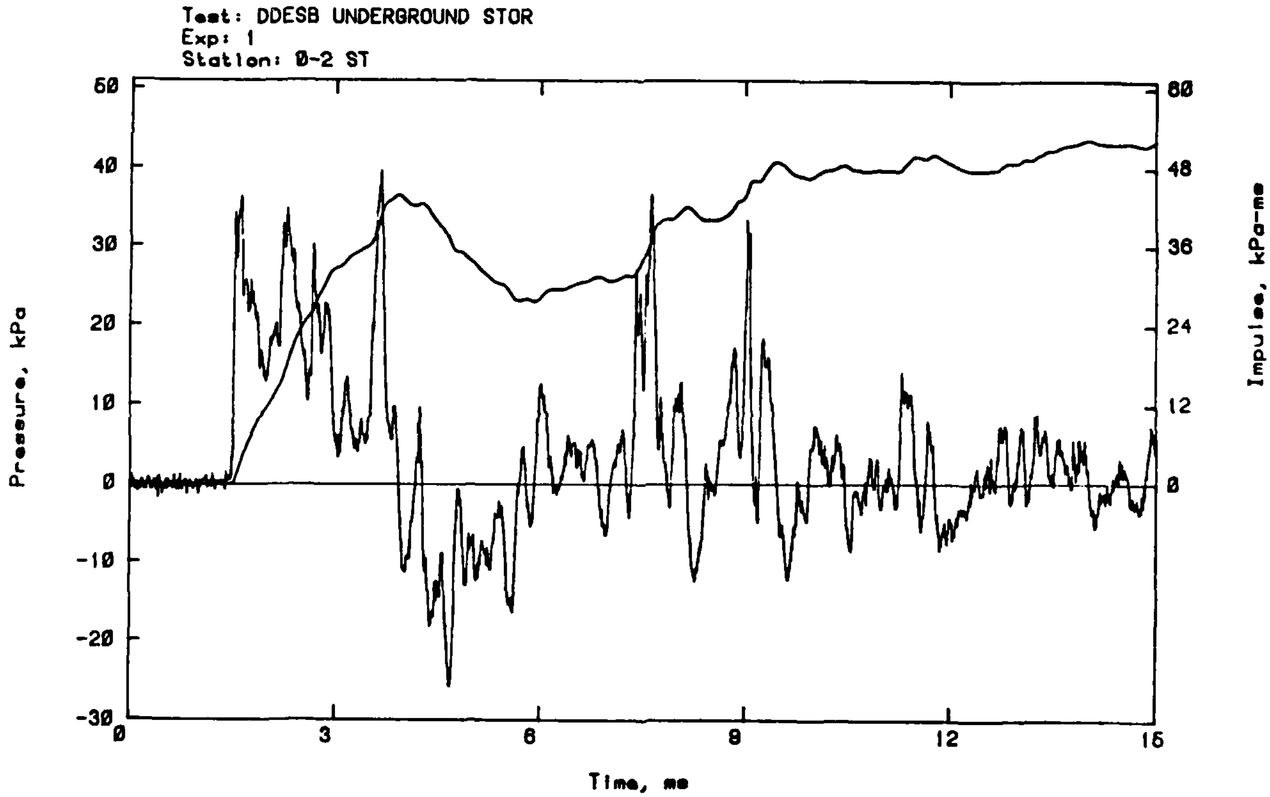
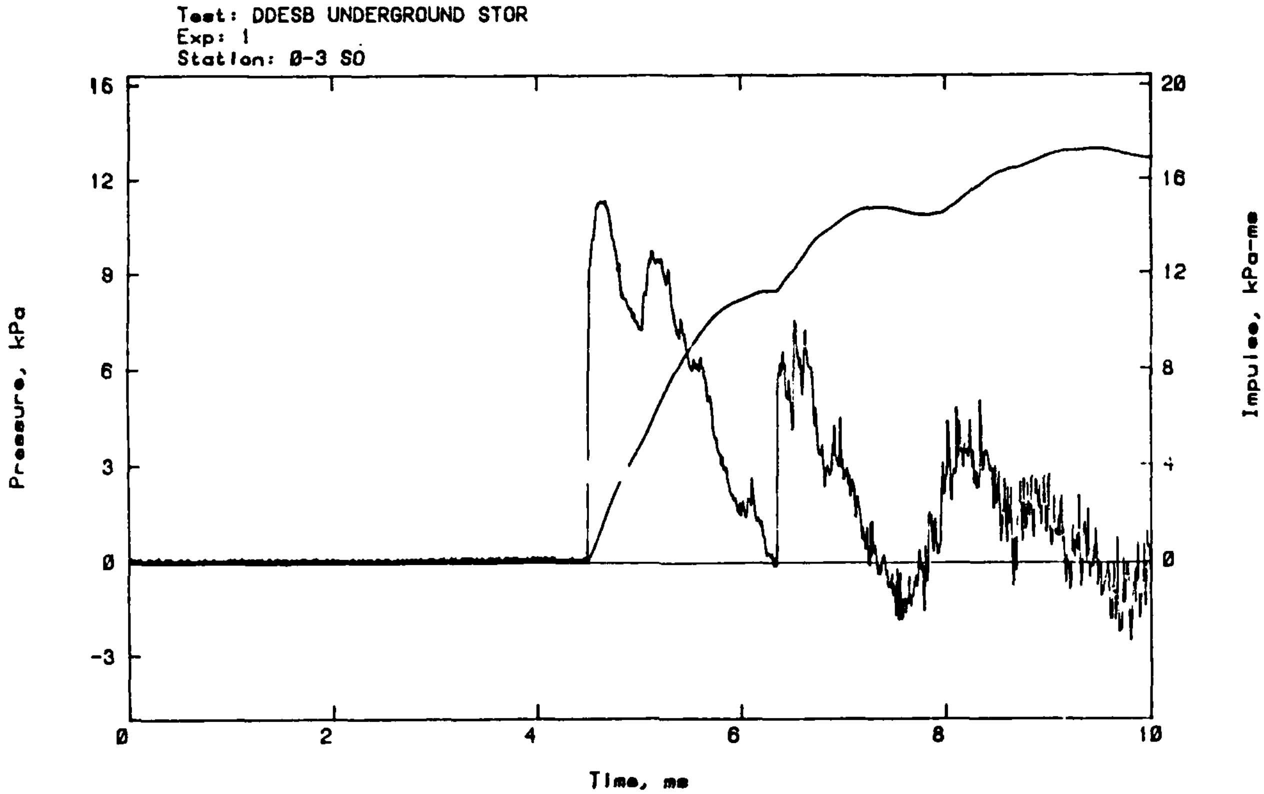
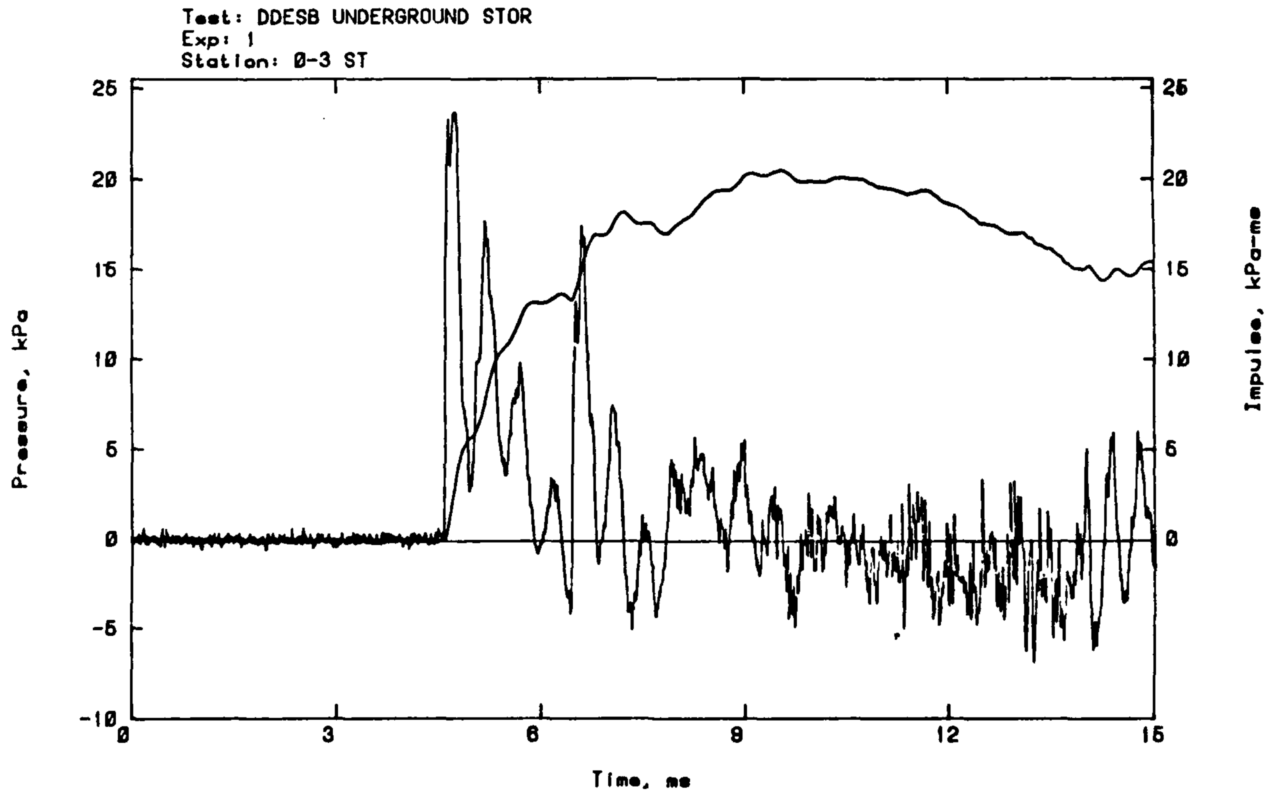


Figure A-1. Shot 1, chamber-loading density 0.681 kg/m³, sand base.





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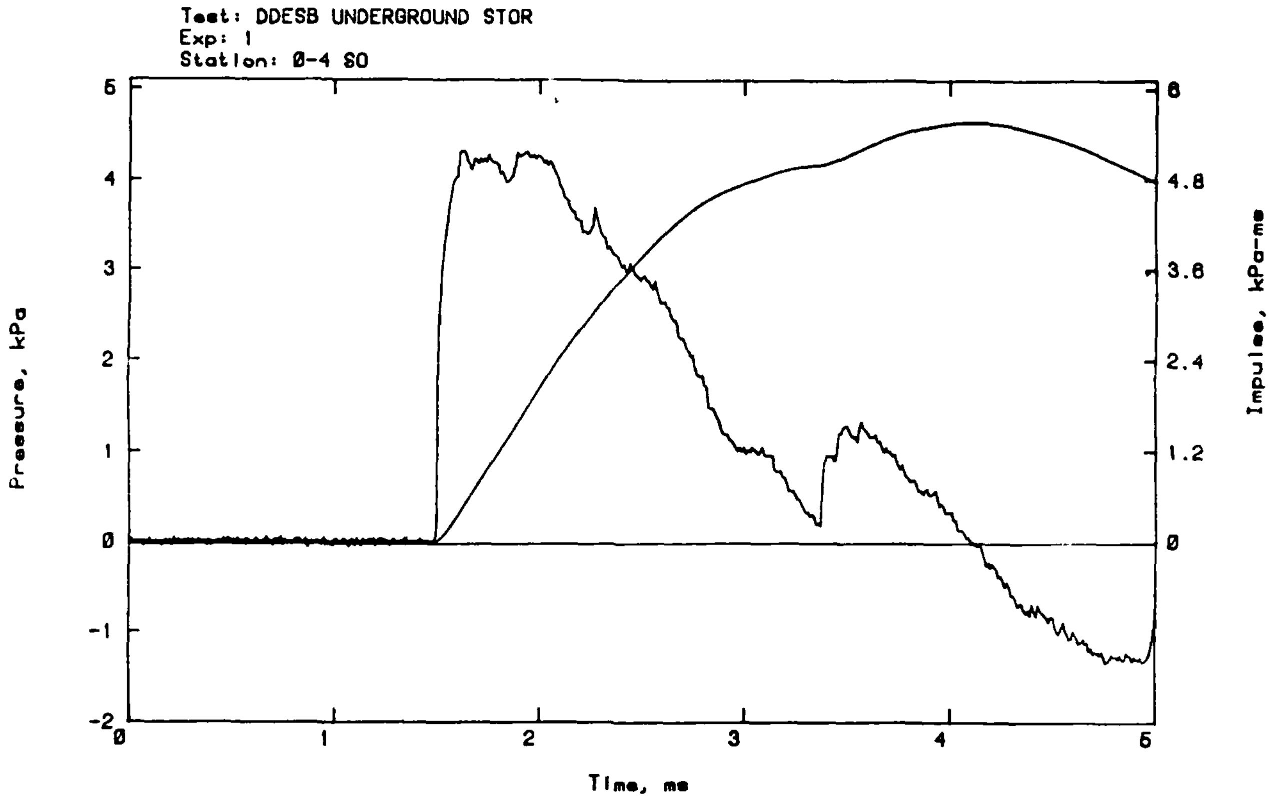

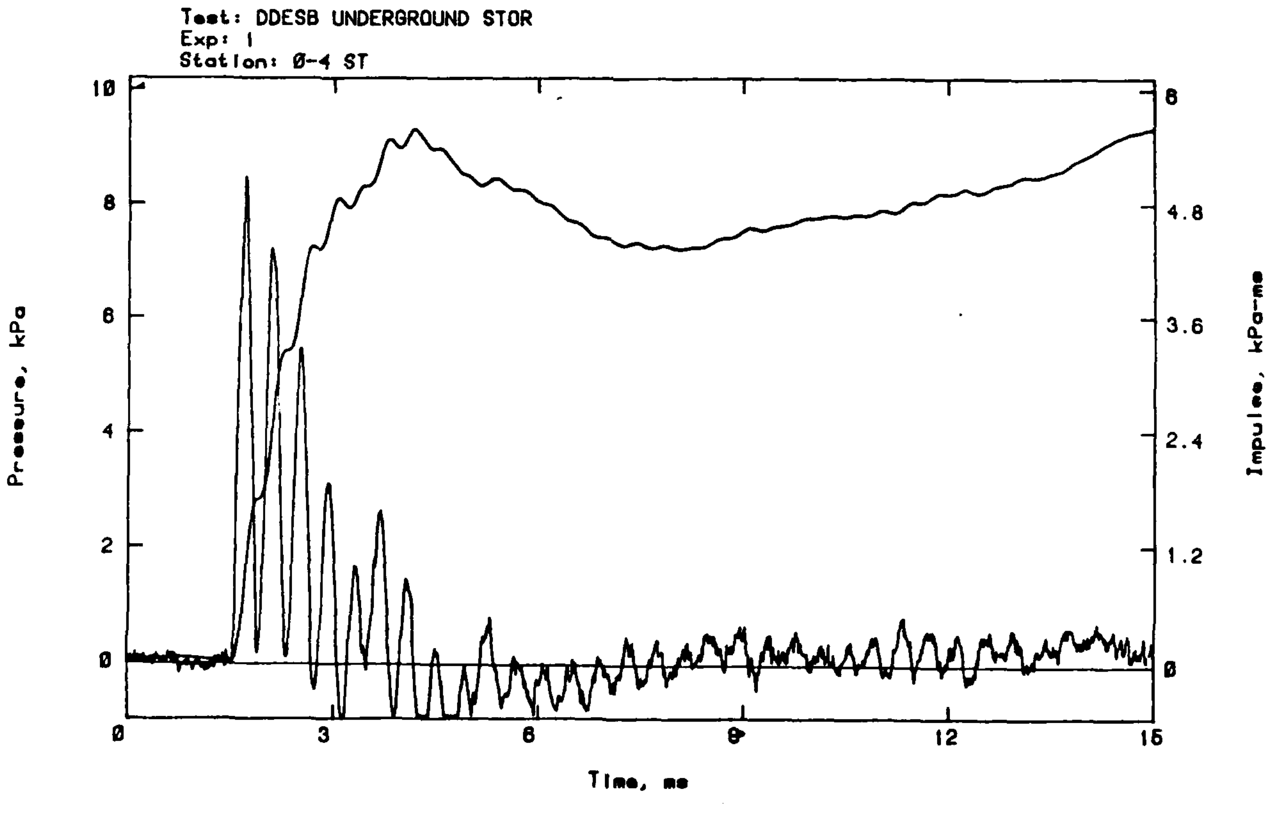

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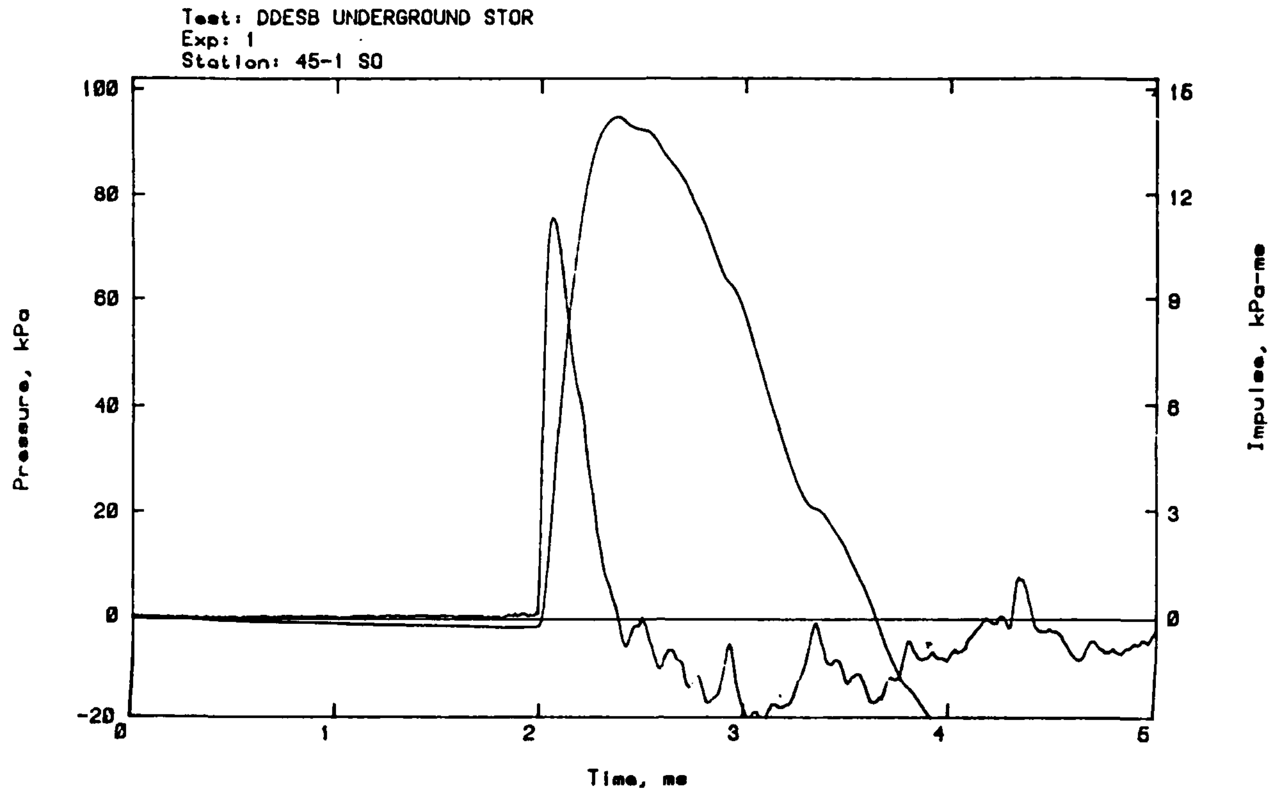

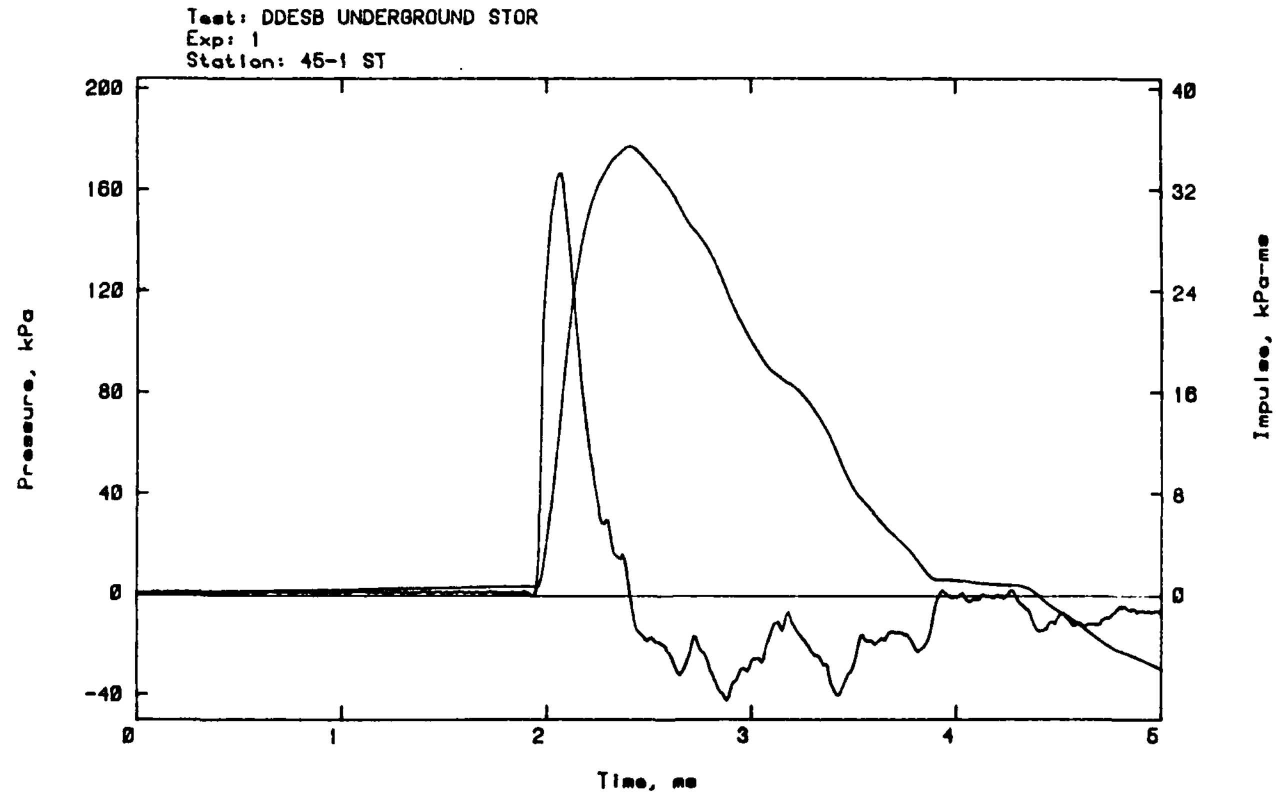

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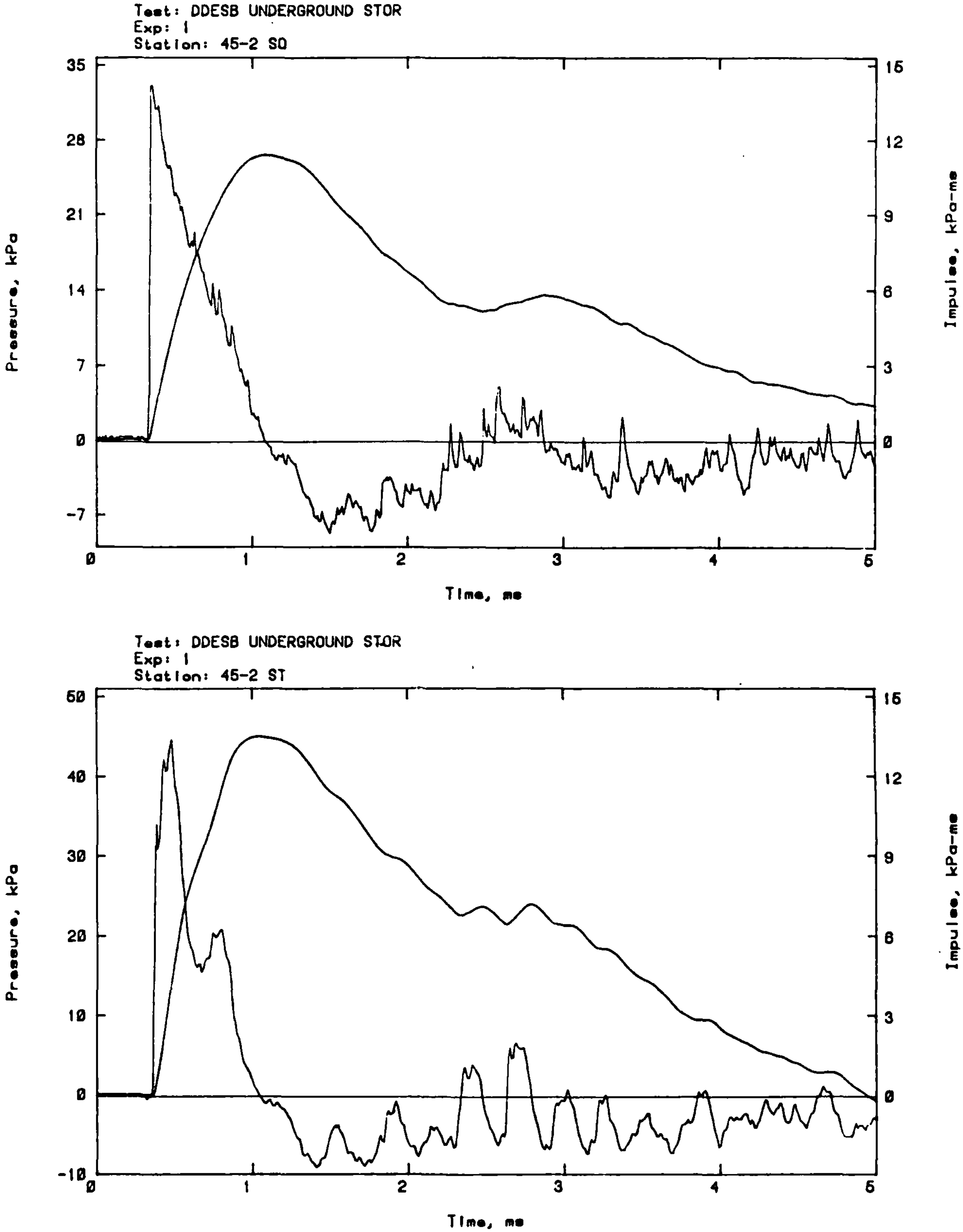

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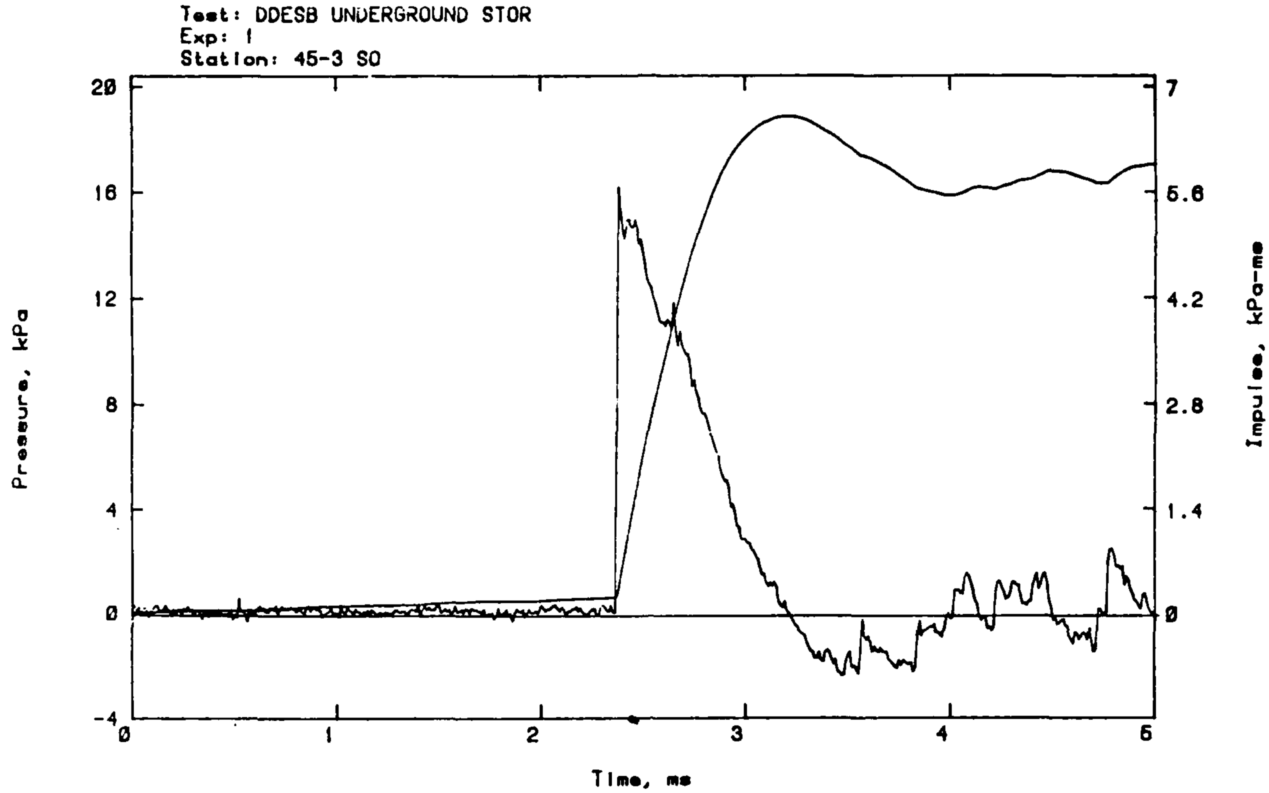

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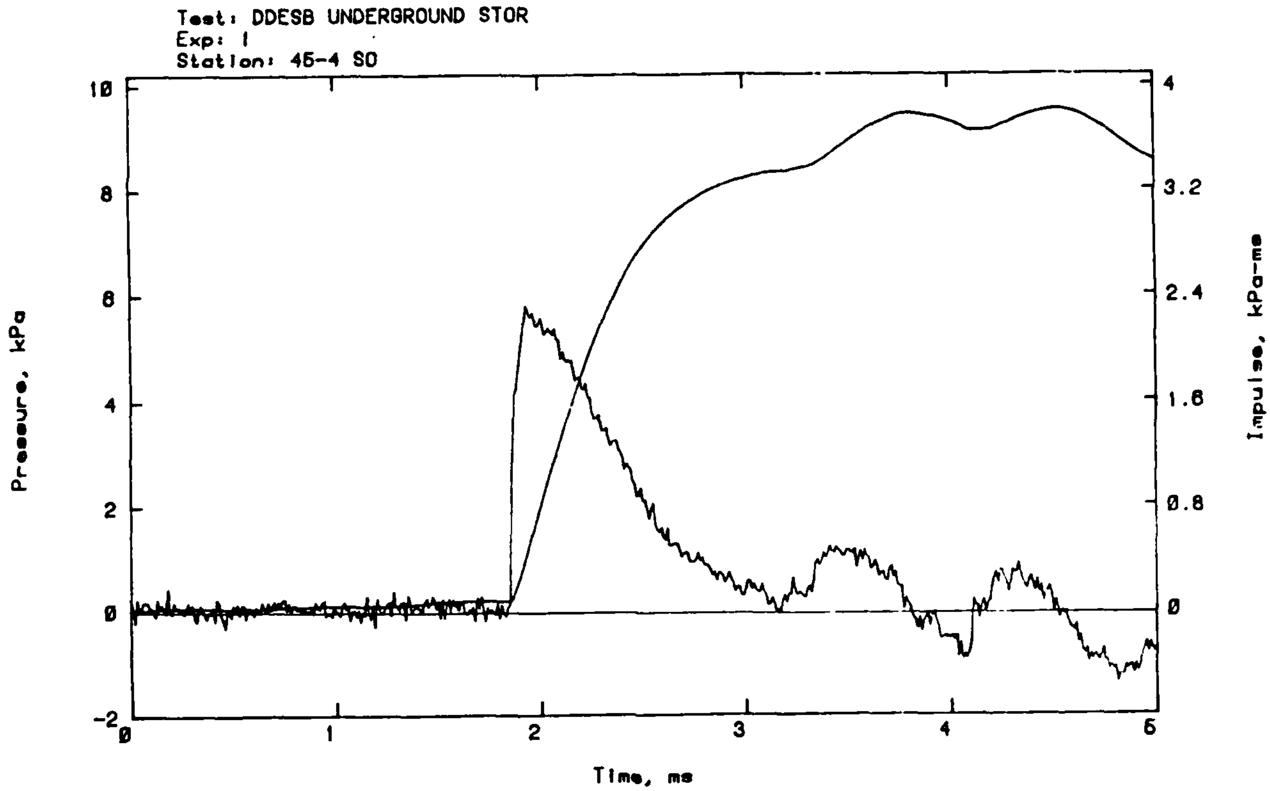
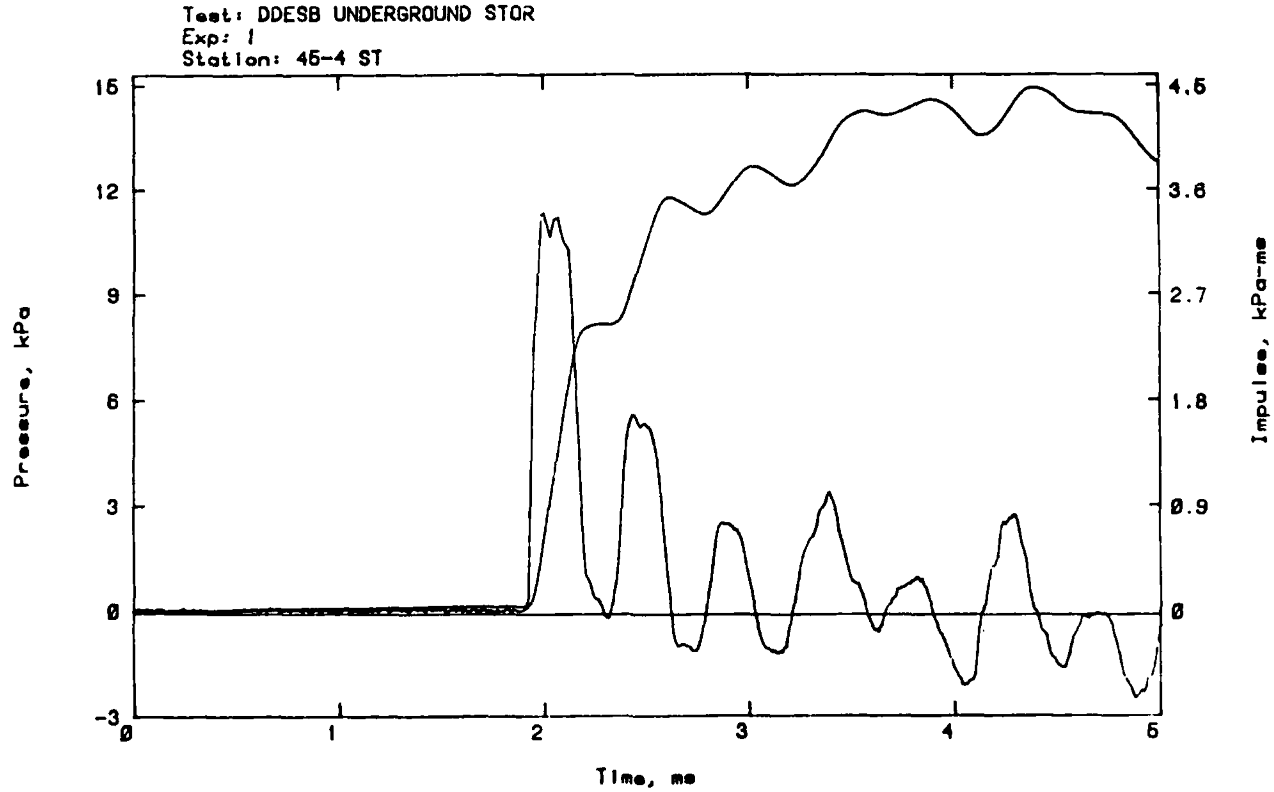
Figure A-1. Shot 1, chamber-loading density 0.681 kg/m^3, sand base.





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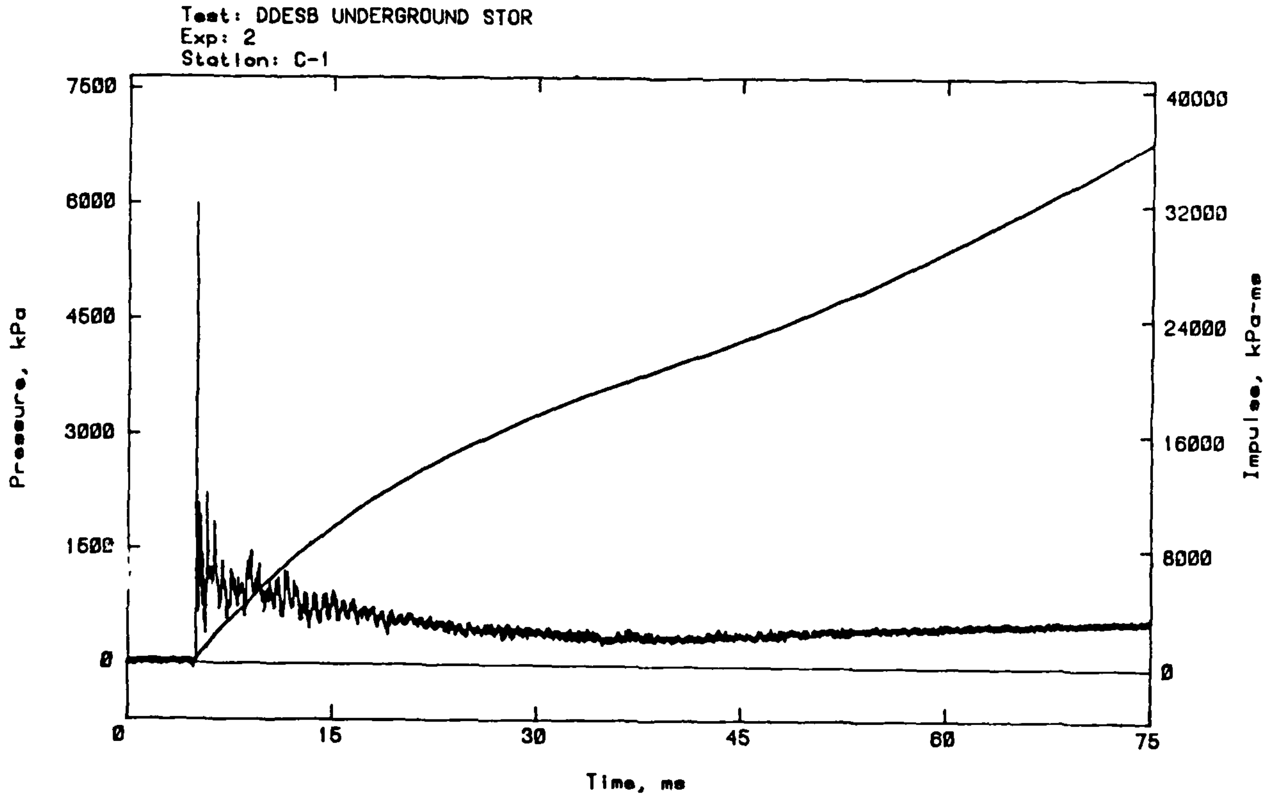


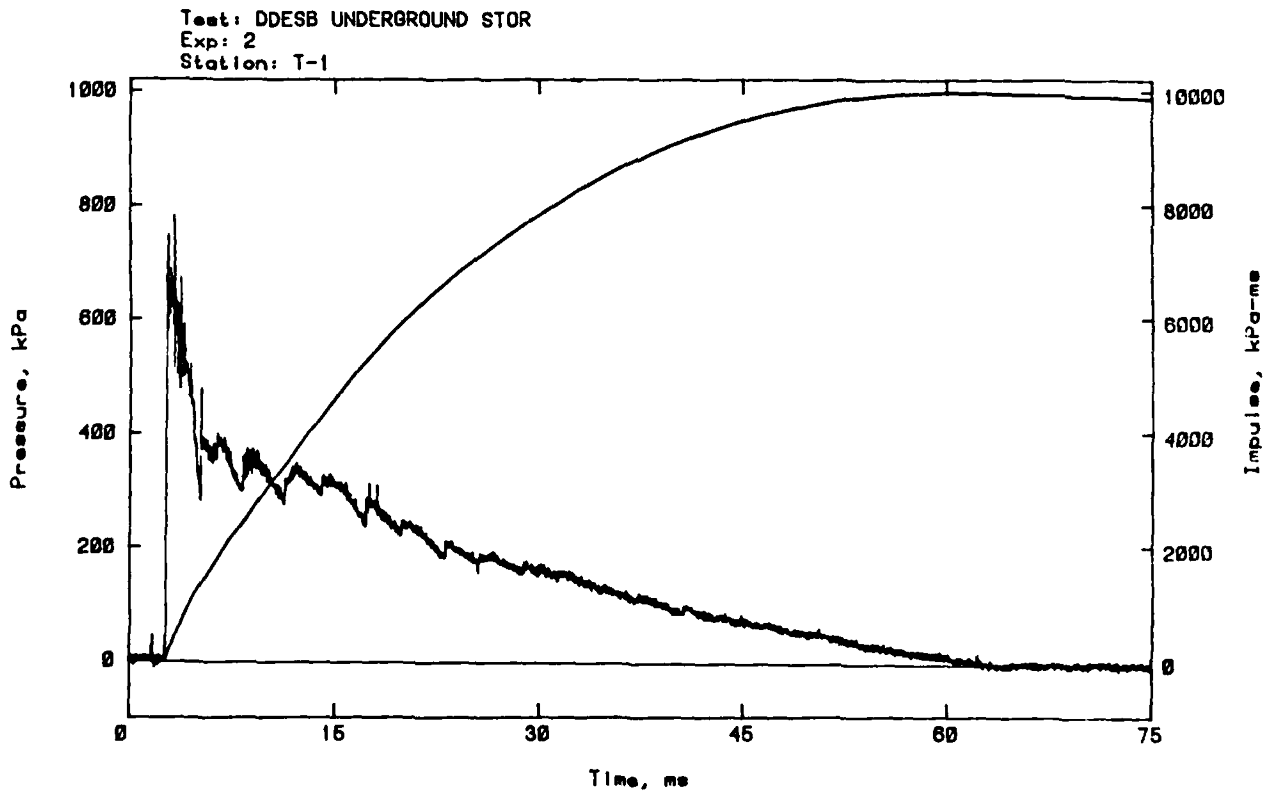
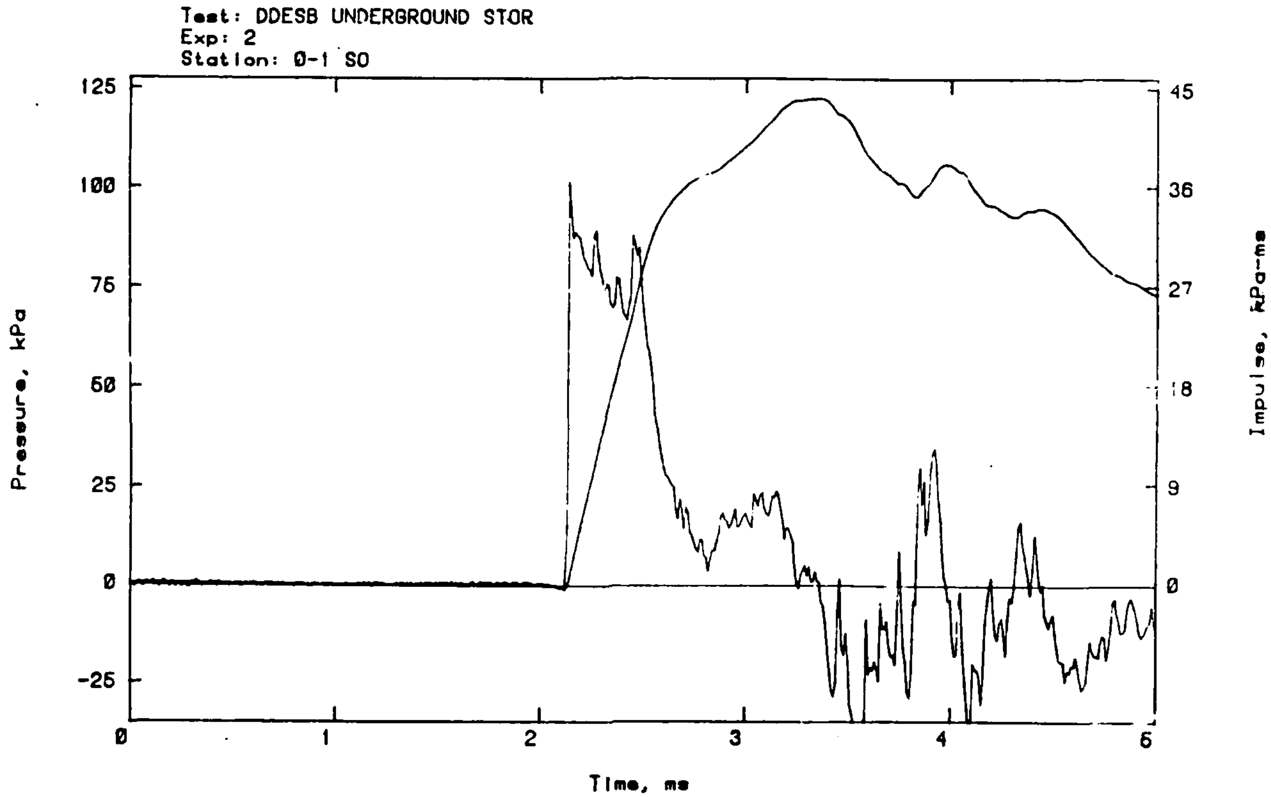


Figure A-2. Shot 2, chamber-loading density 0.681 kg/m³, sand base.



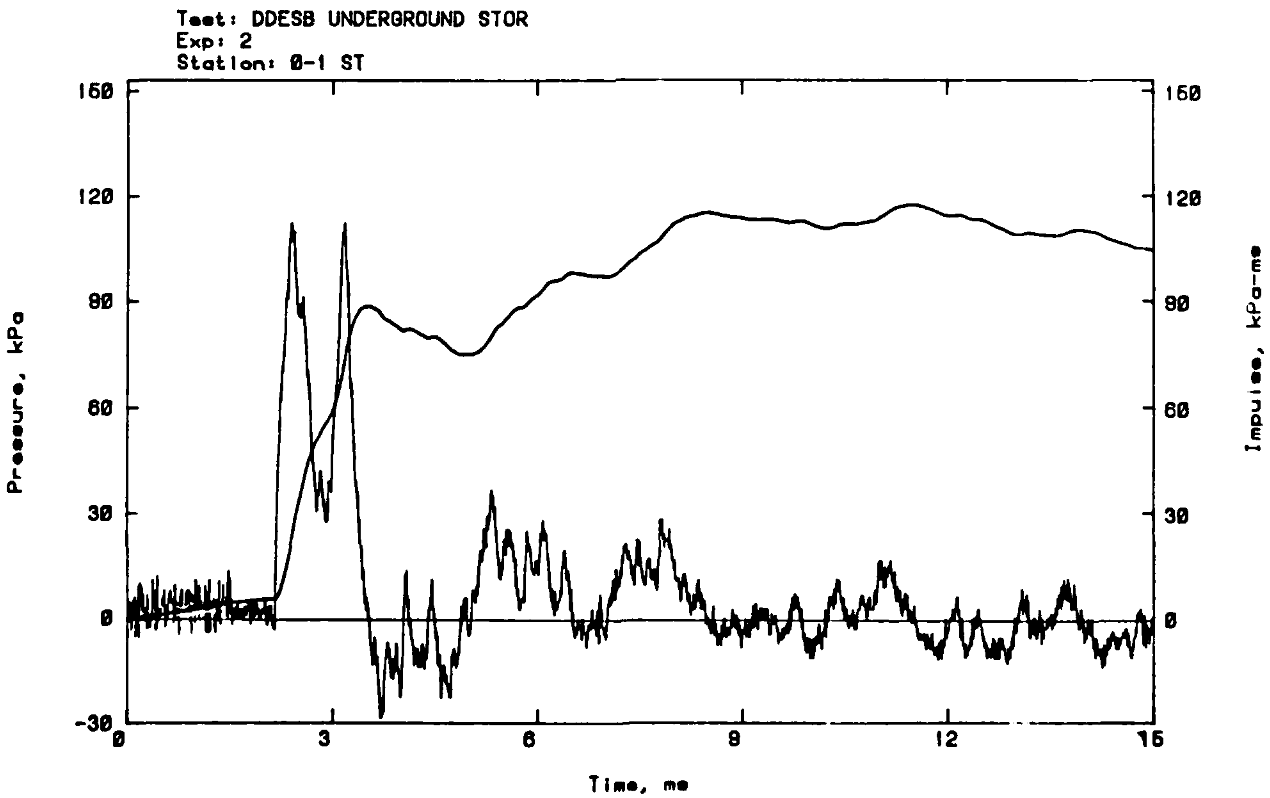
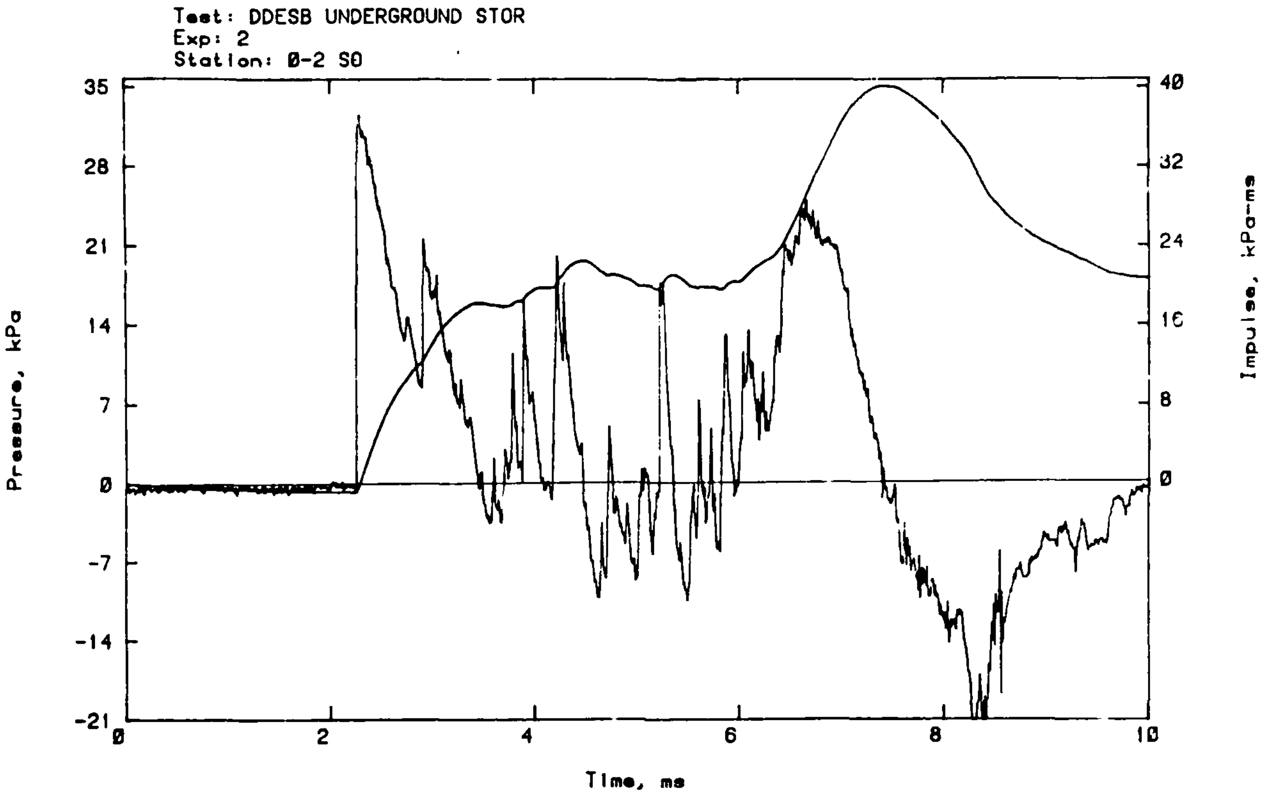


Figure A-2. Shot 2, chamber-loading density 0.681 kg/m³, sand base.



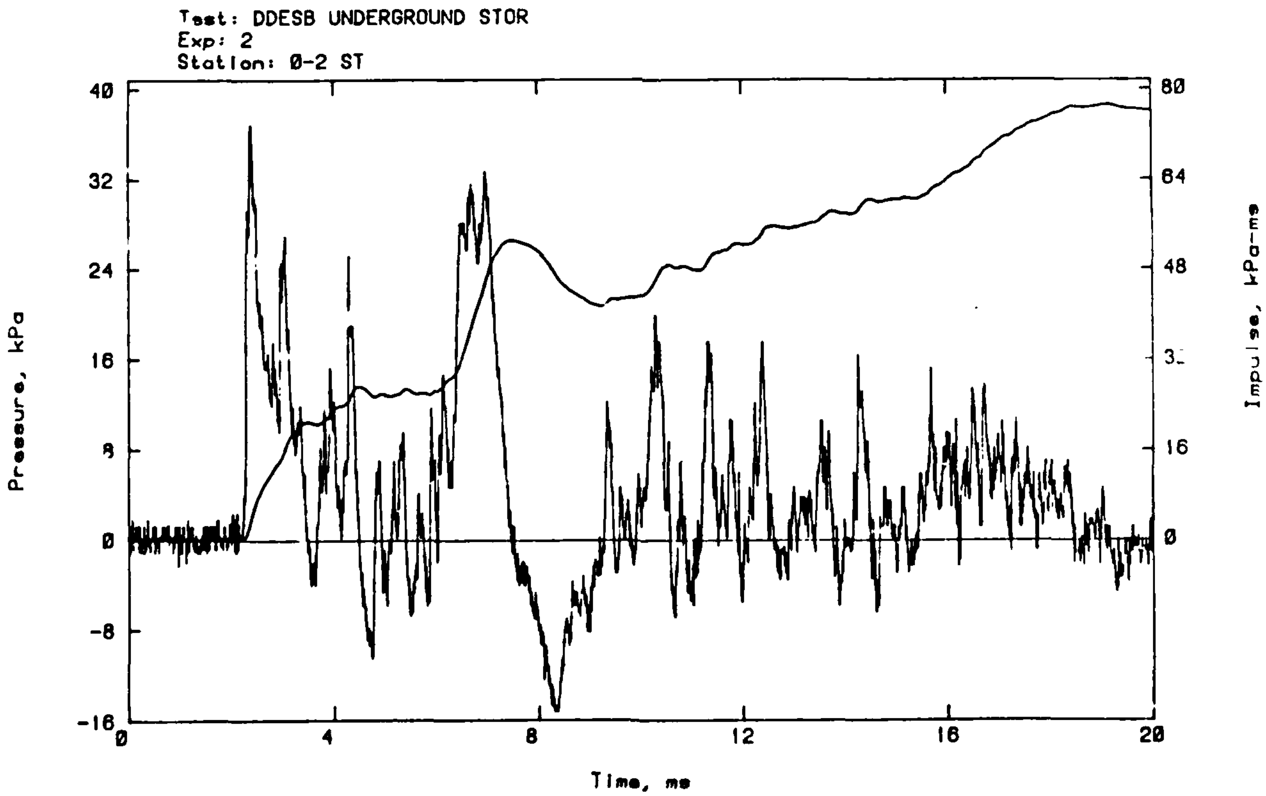
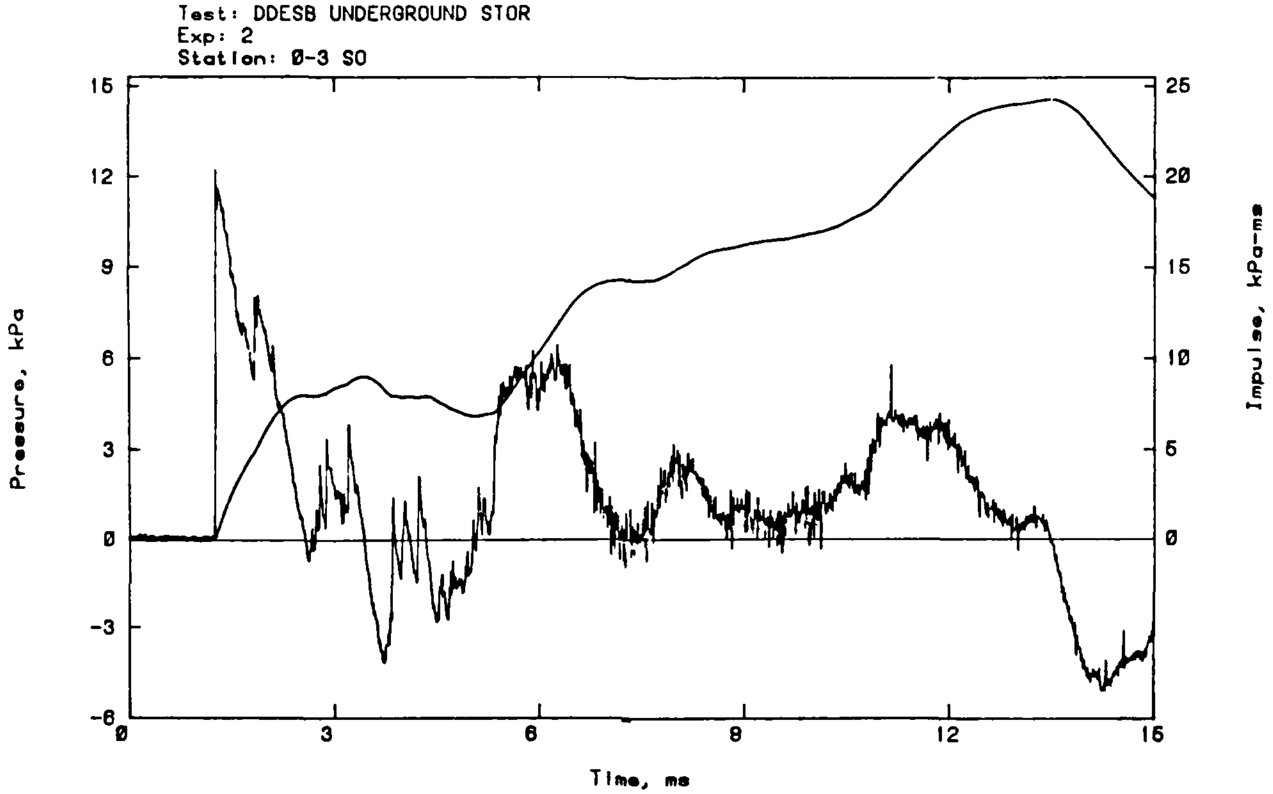


Figure A-2. Shot 2, chamber-loading density 0.681 kg/m^3, sand base.



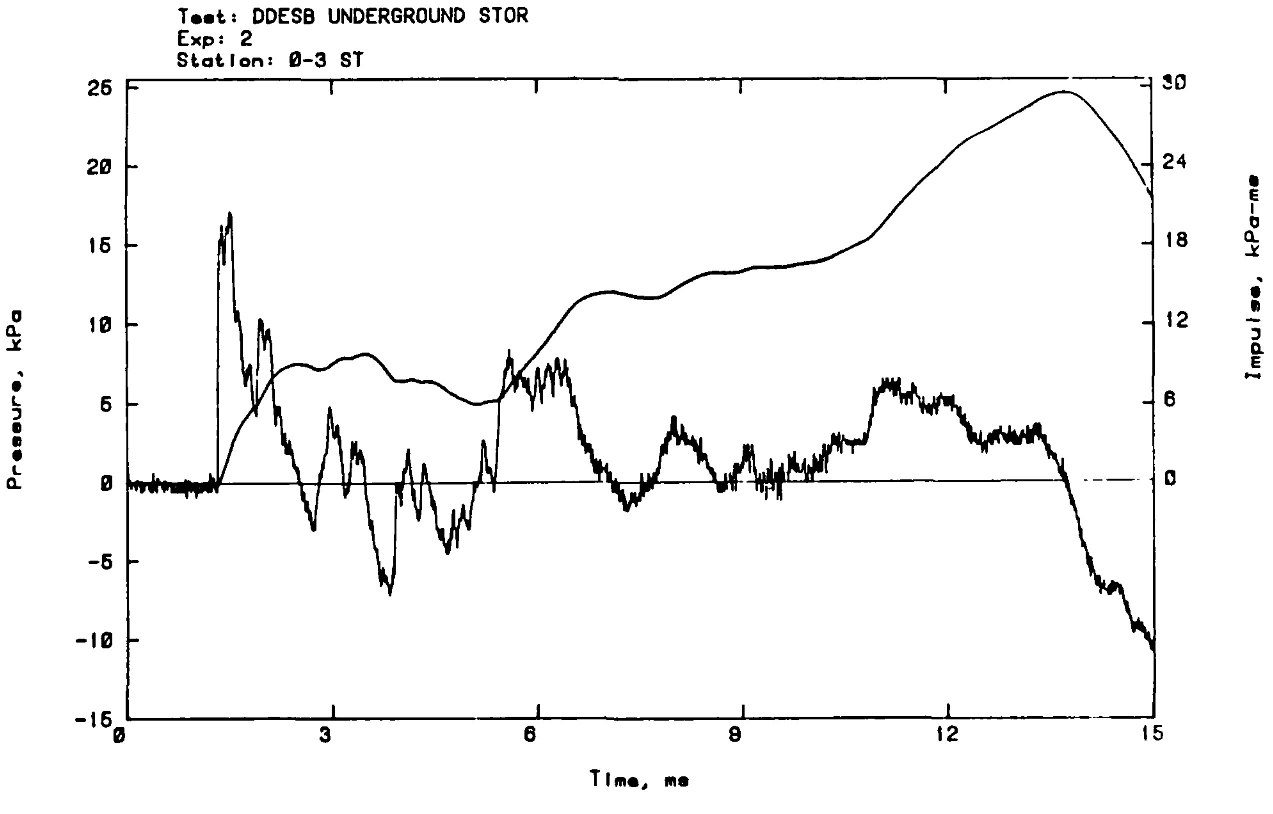
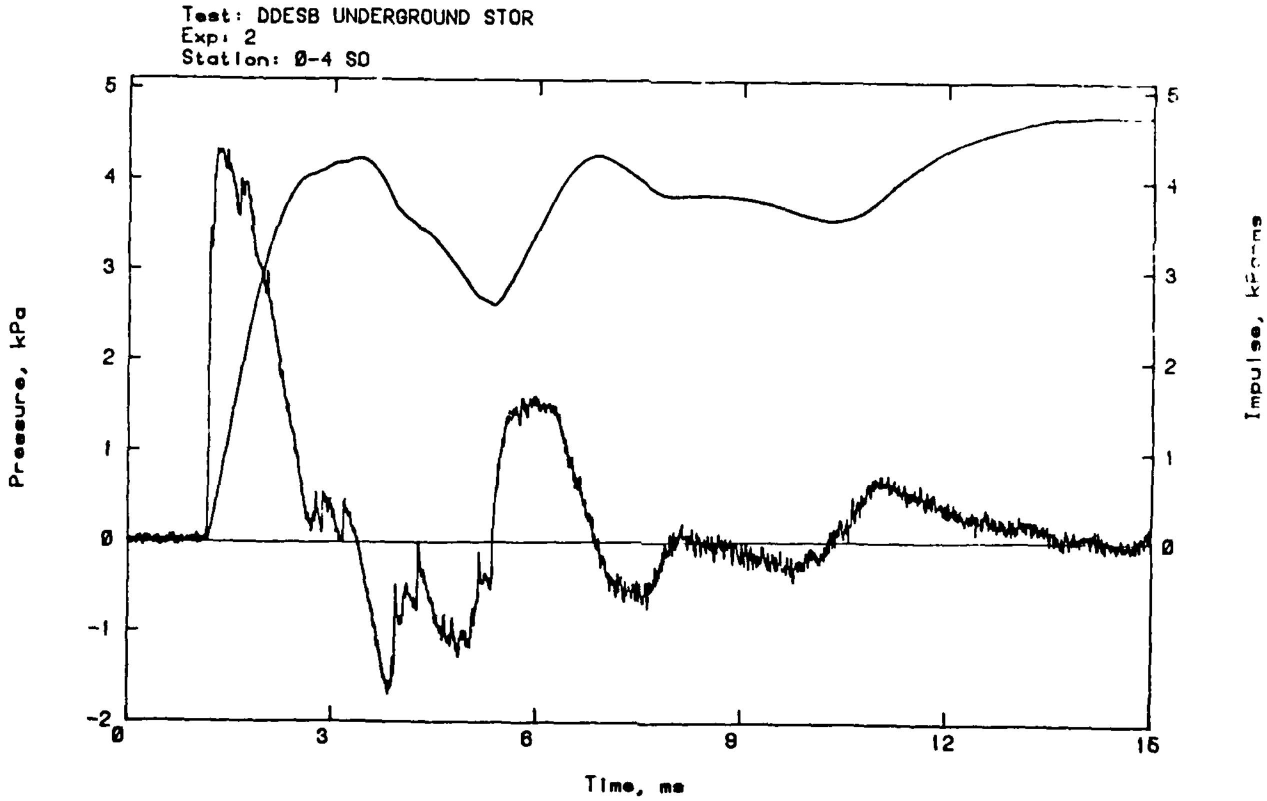


Figure A-2. Shot 2, chamber-loading density 0.681 kg/m³, sand base.



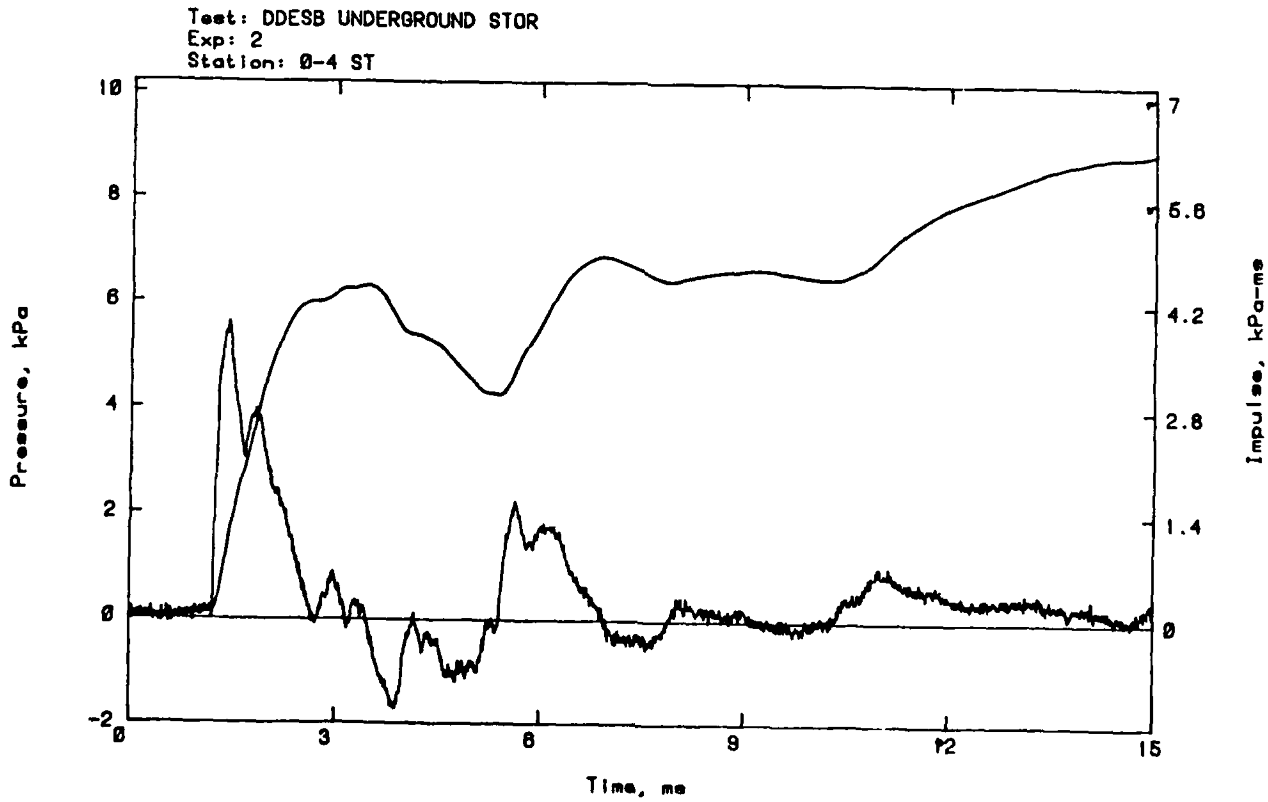
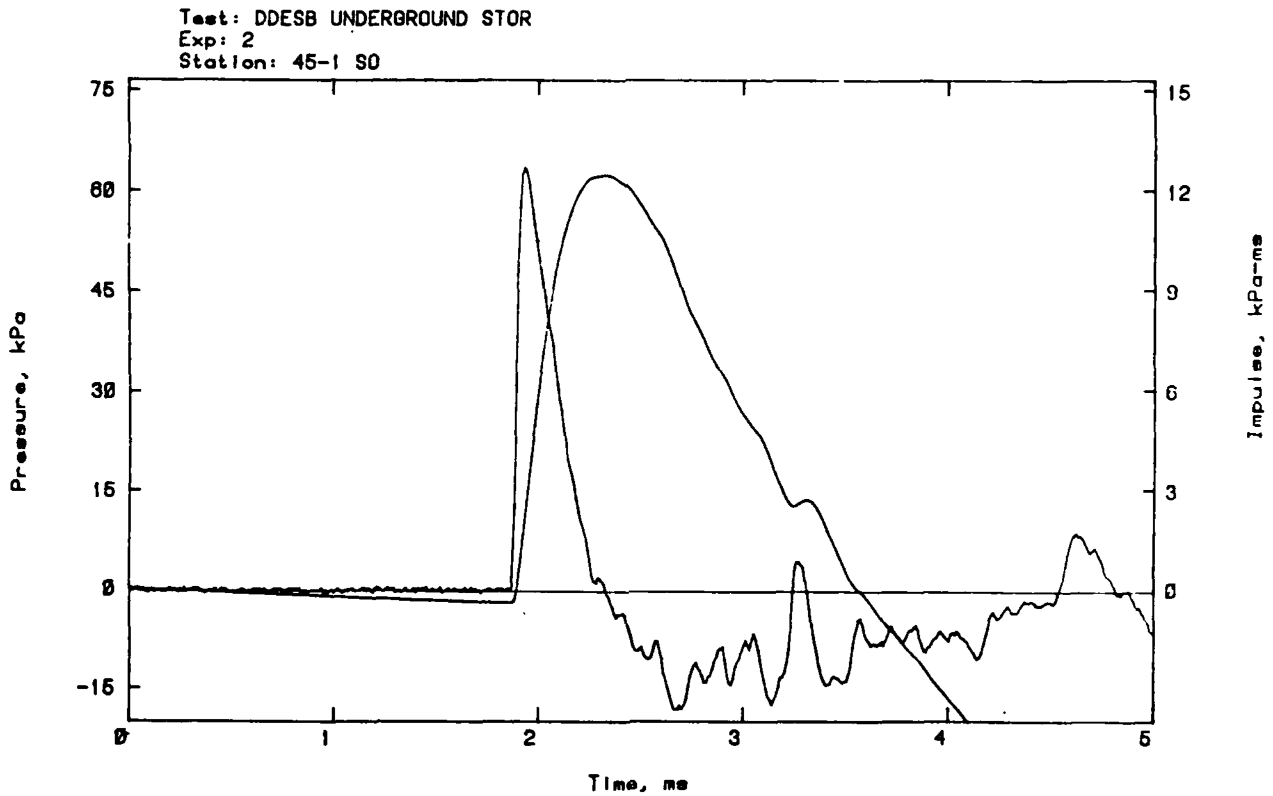


Figure A-2. Shot 2, chamber-loading density 0.681 kg/m^3, sand base.



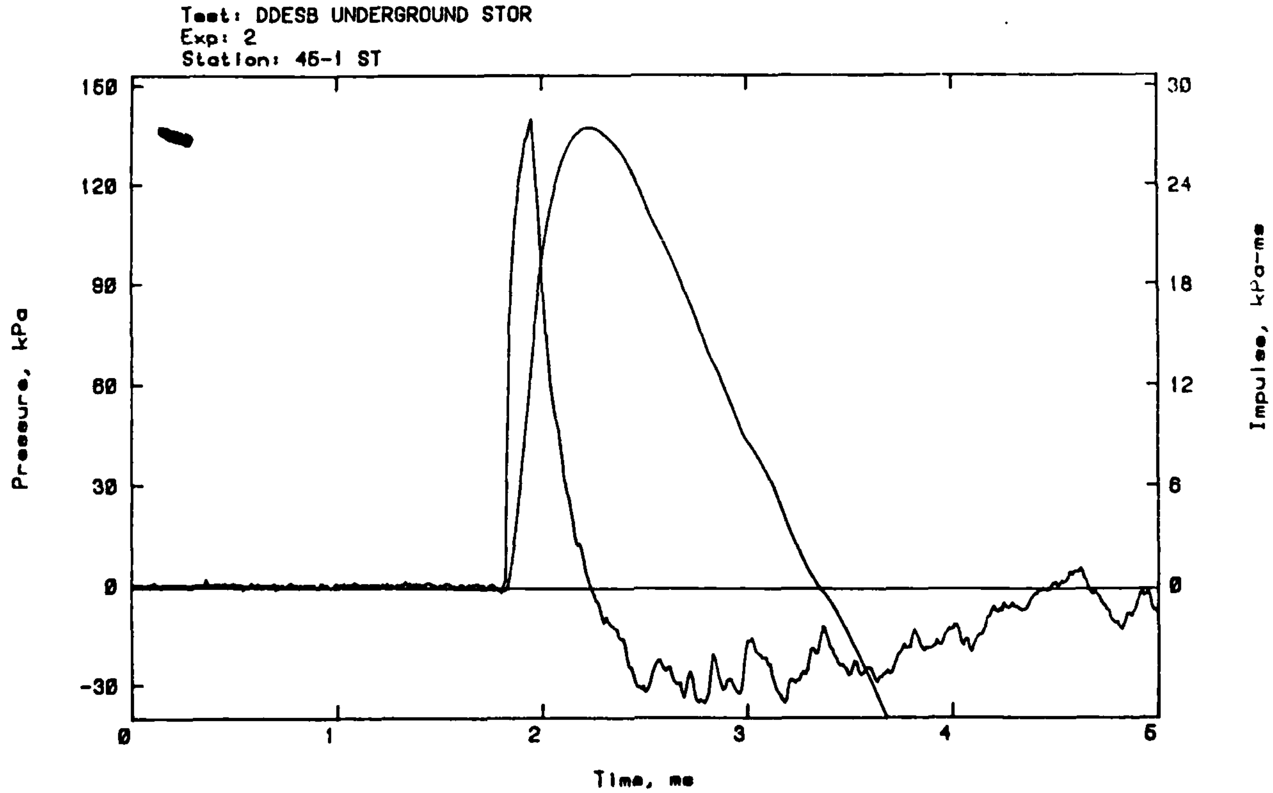
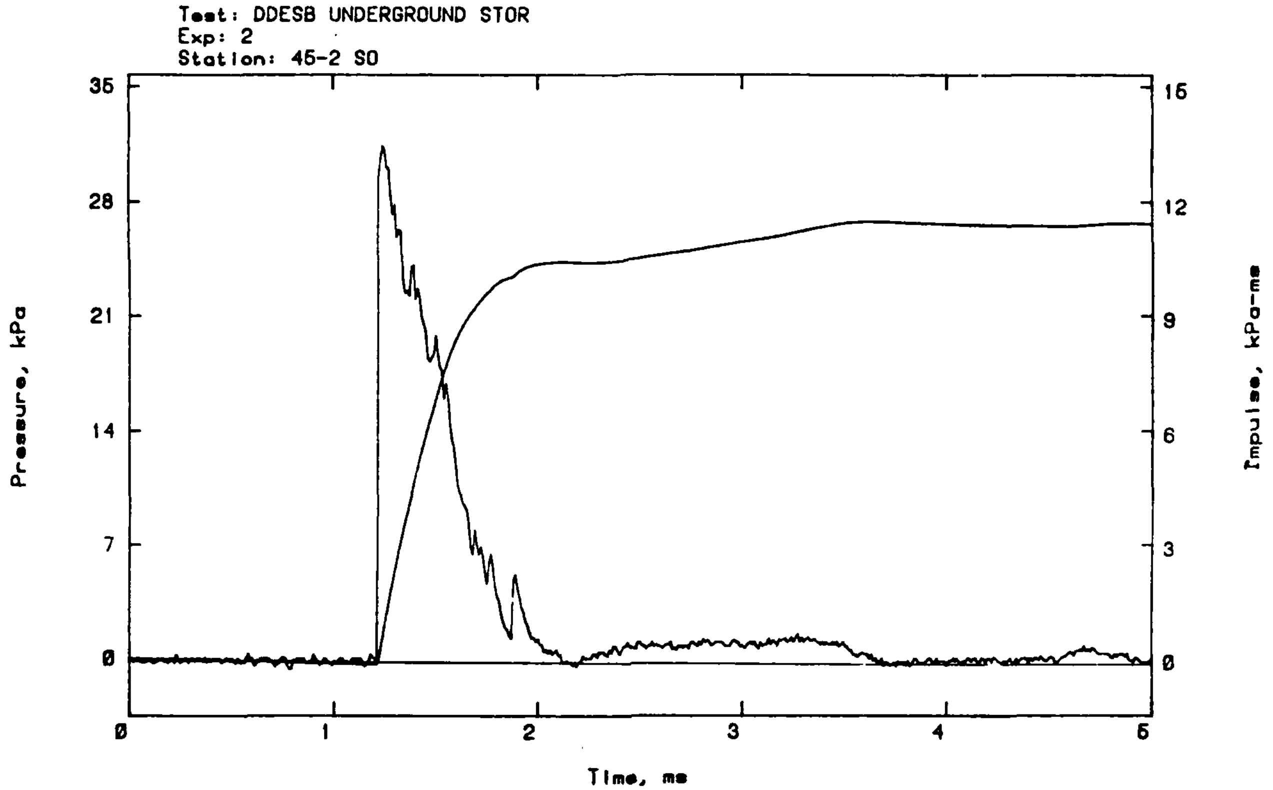


Figure A-2. Shot 2, chamber-loading density 0.681 kg/m^3, sand base.



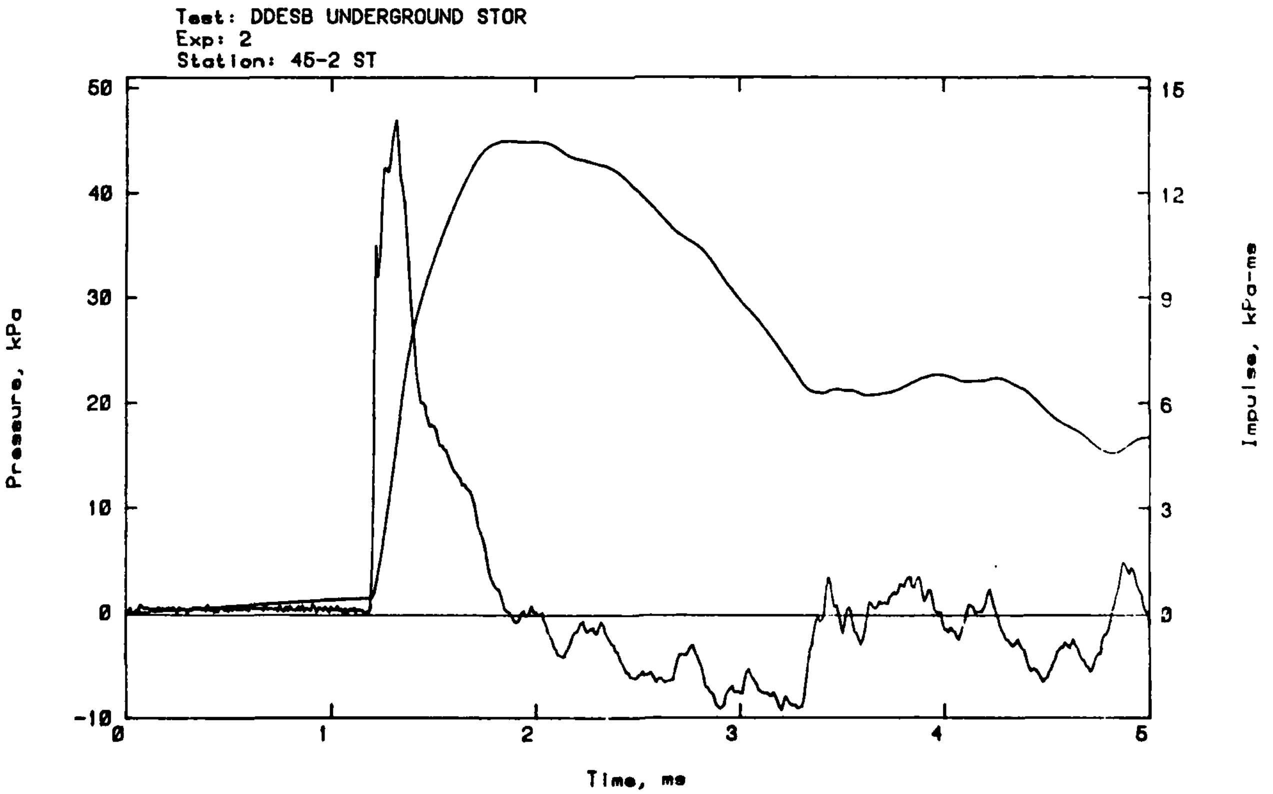
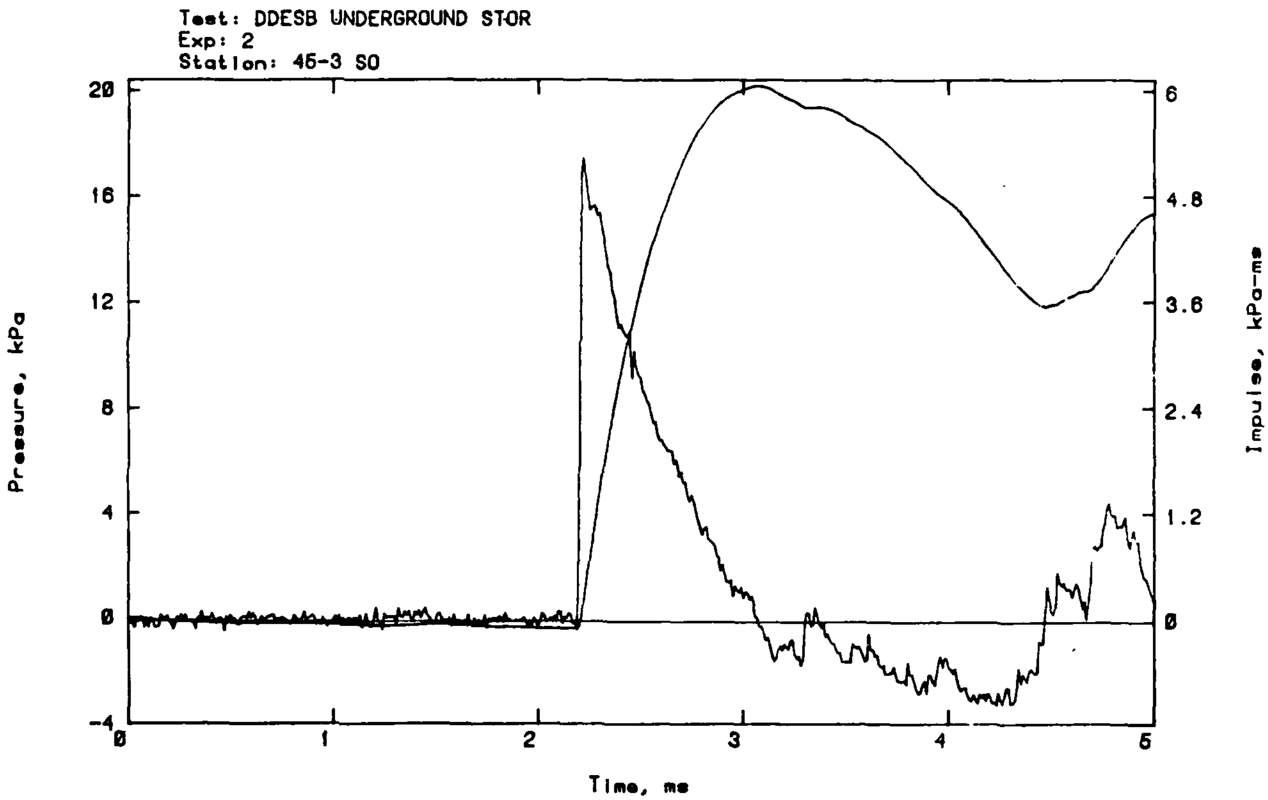
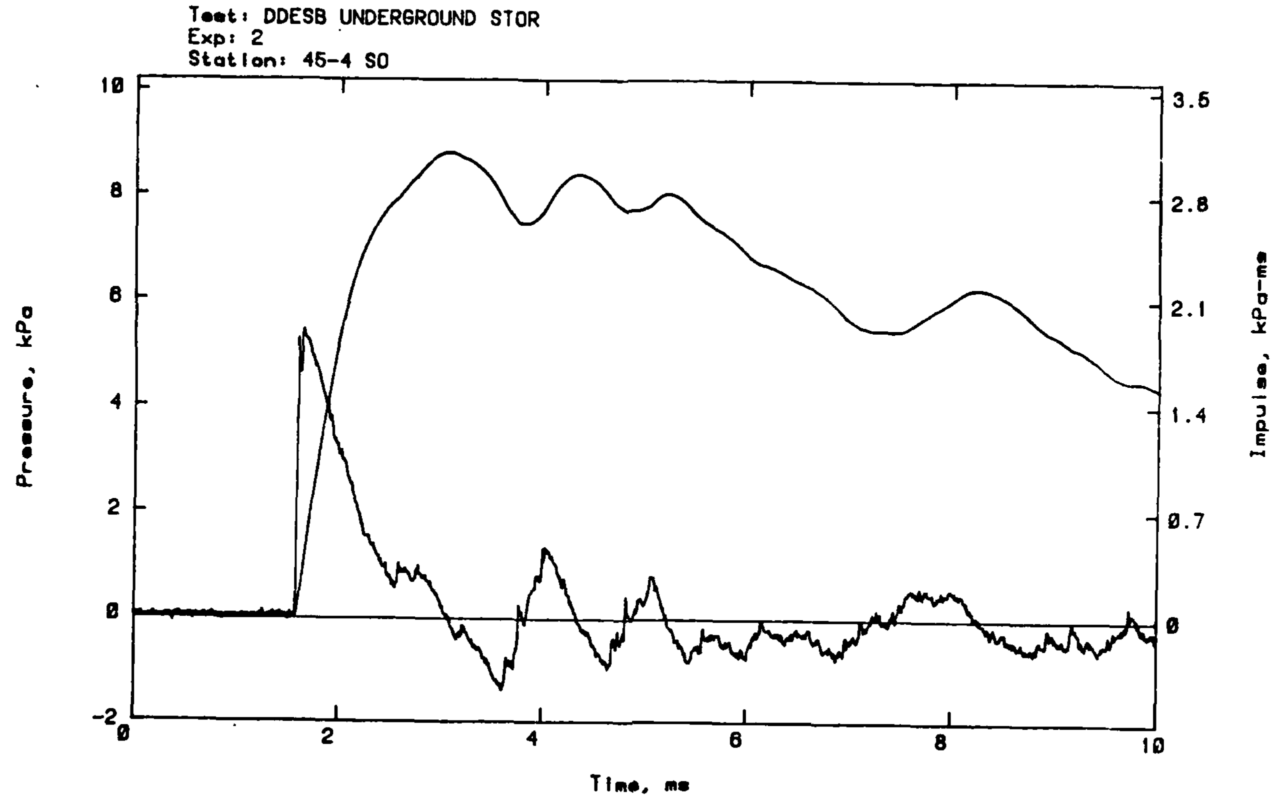


Figure A-2. Shot 2, chamber-loading density 0.681 kg/m^3, sand base.



STATION 45-3 ST CURVE IS NOT AVAILABLE.

Figure A-2. Shot 2, chamber-loading density 0.681 kg/m^3, sand base.



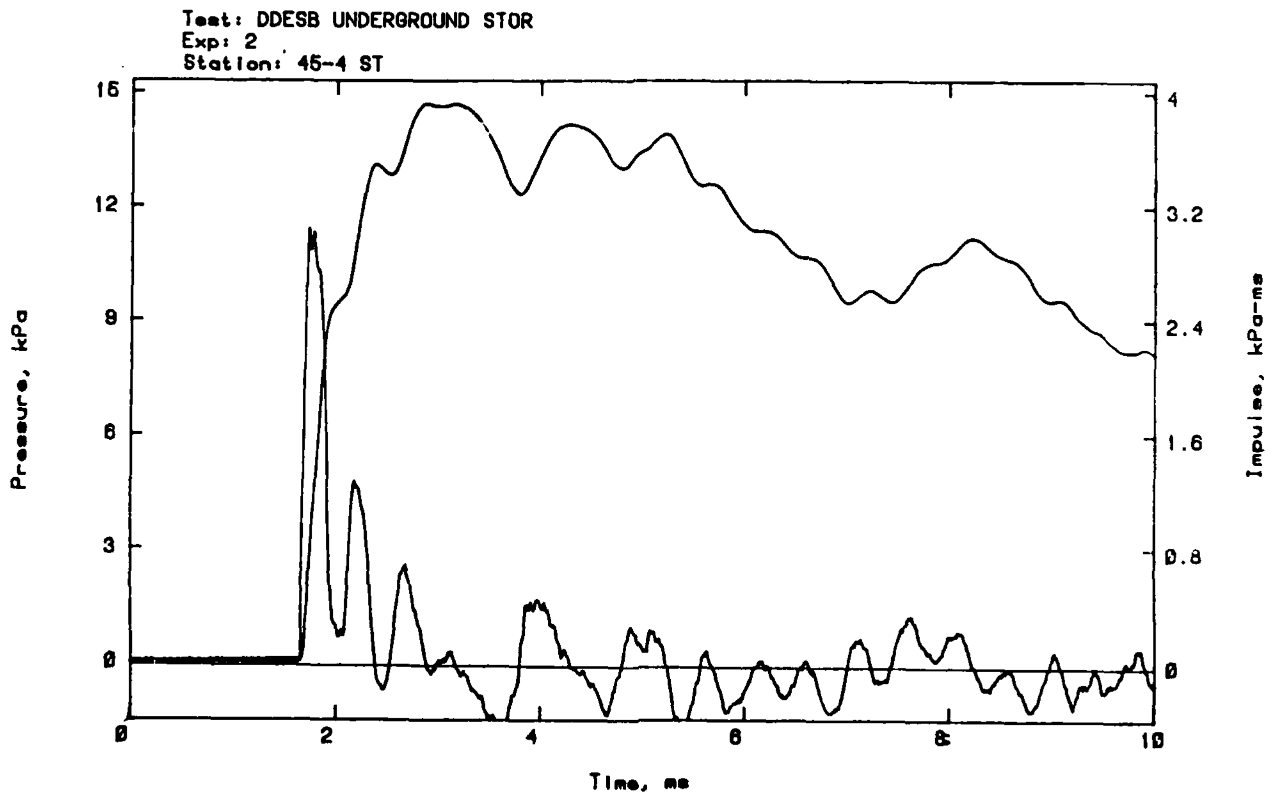


Figure A-2. Shot 2, chamber-loading density 0.681 kg/m³, sand base.

Station C-1 curve is not available.

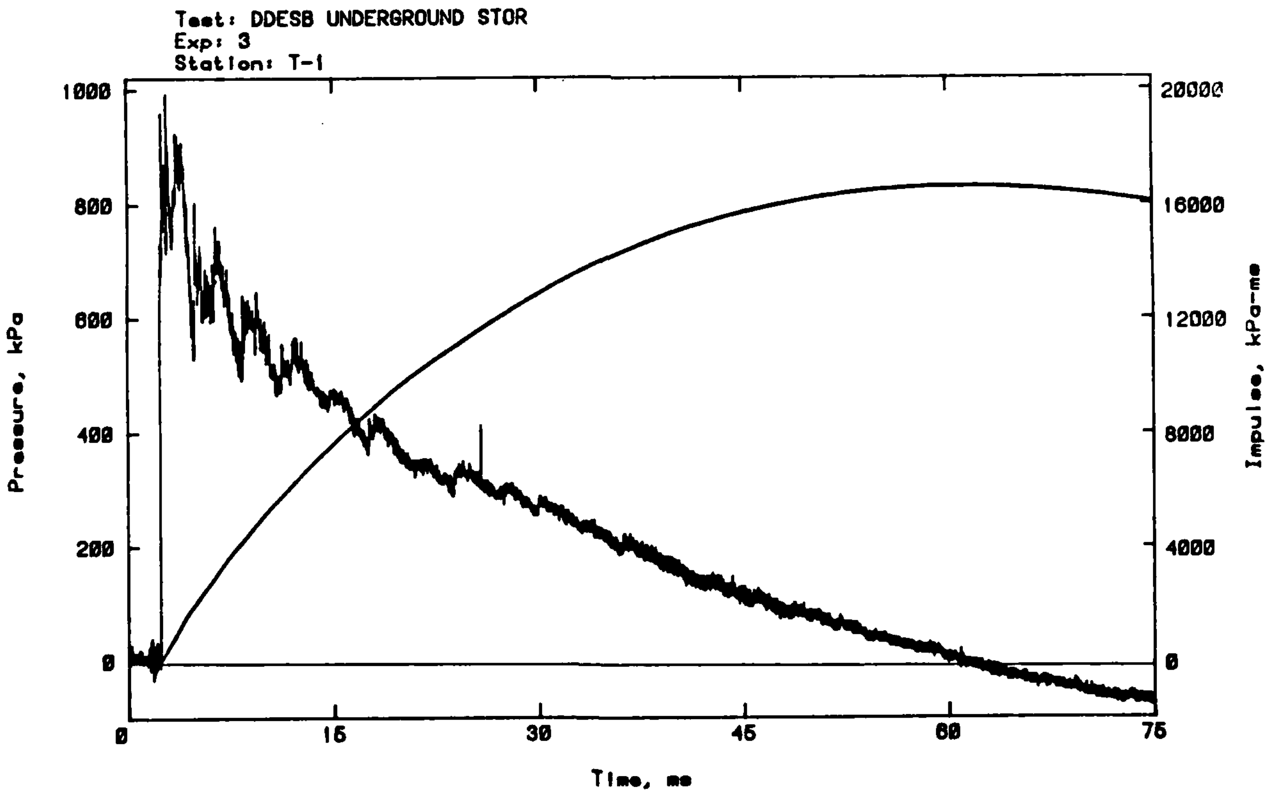
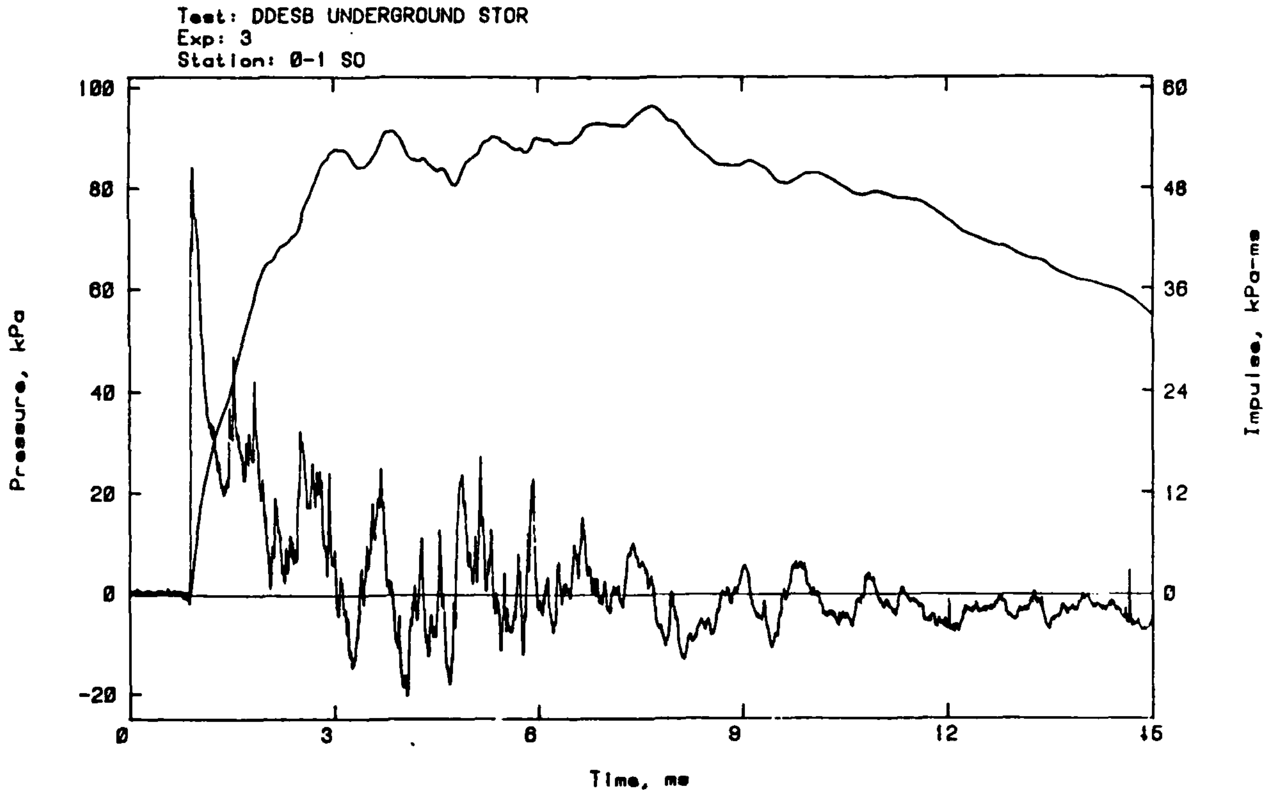


Figure A-3. Shot 3, chamber-loading density 1.46 kg/m³, sand base.



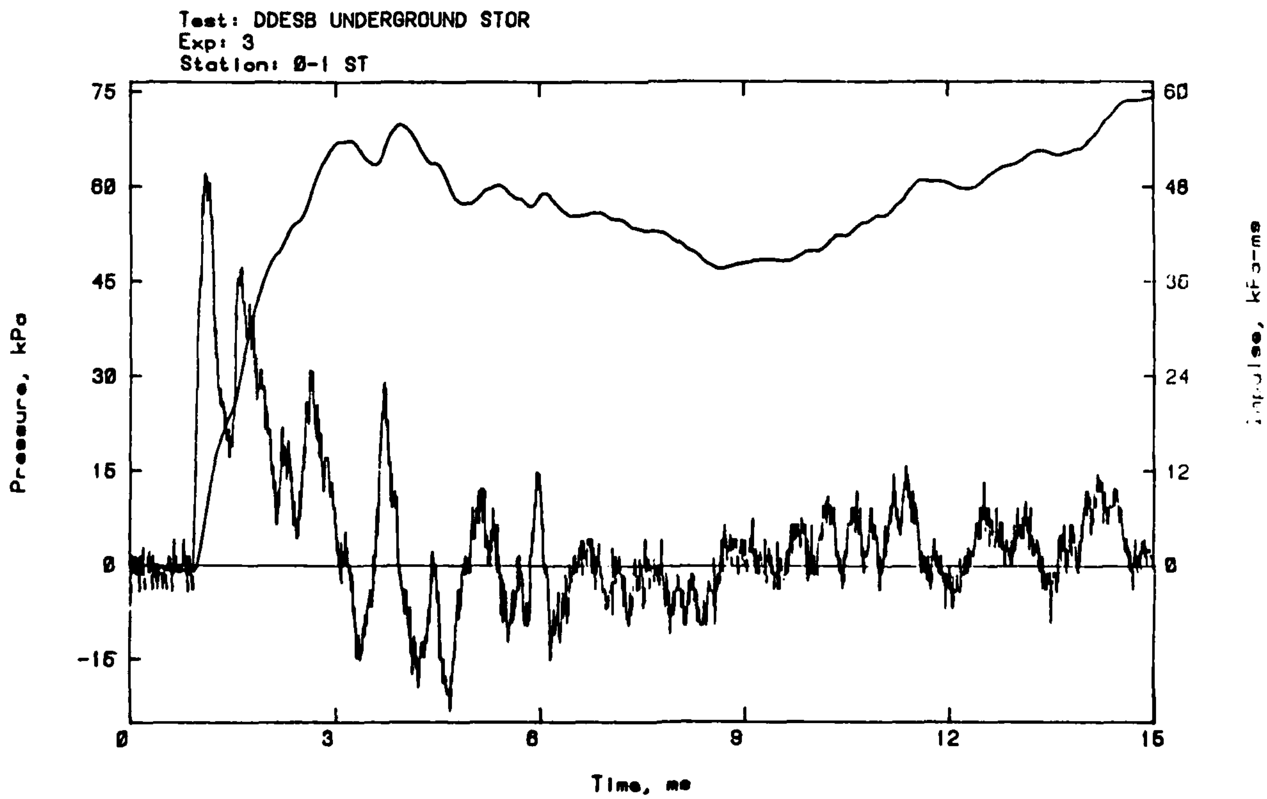
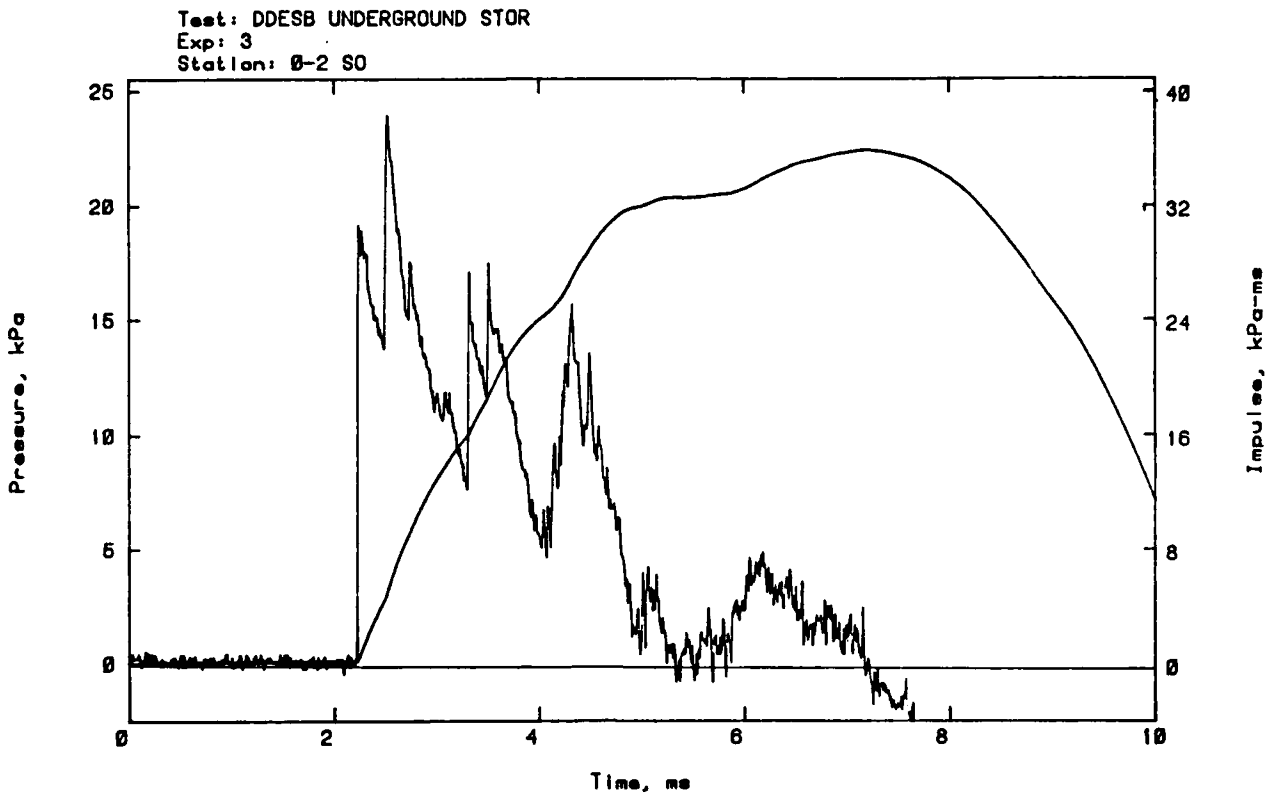


Figure A-3. Shot 3, chamber-loading density 1.46 kg/m³, sand base.



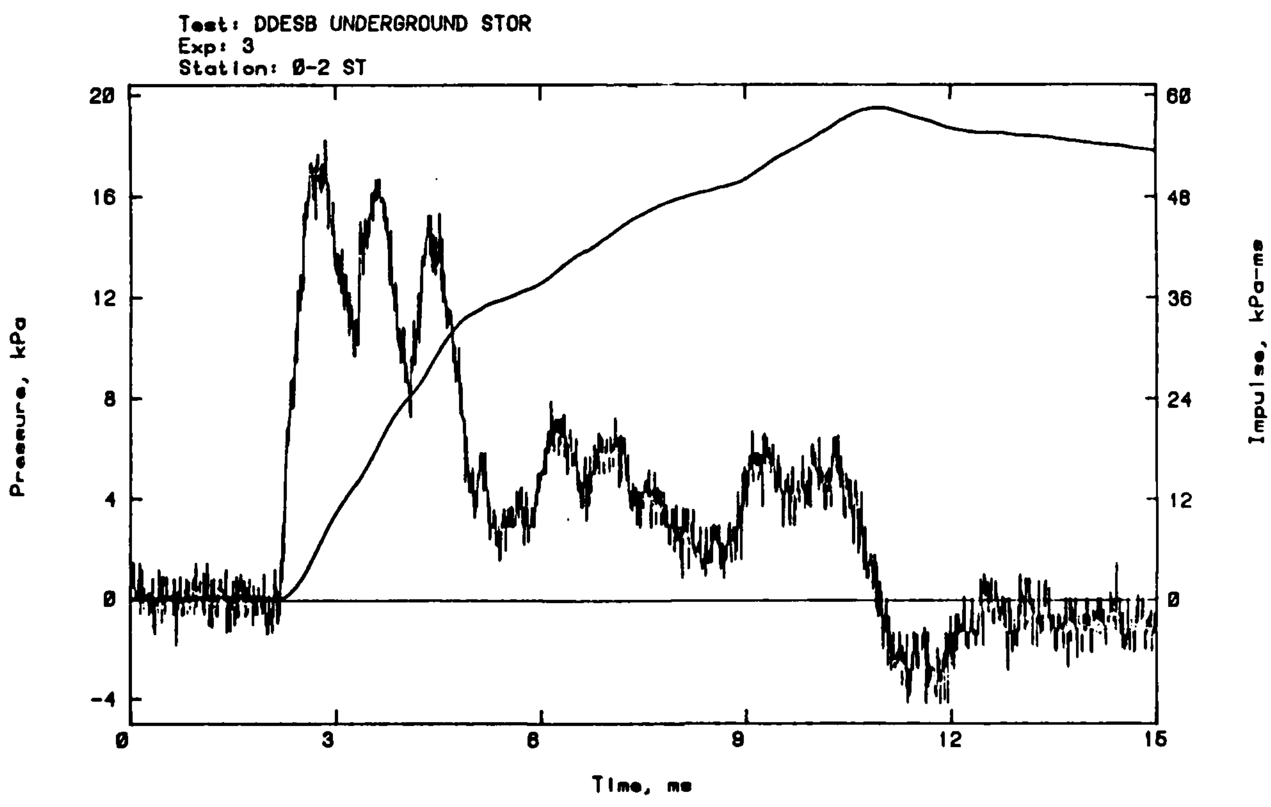
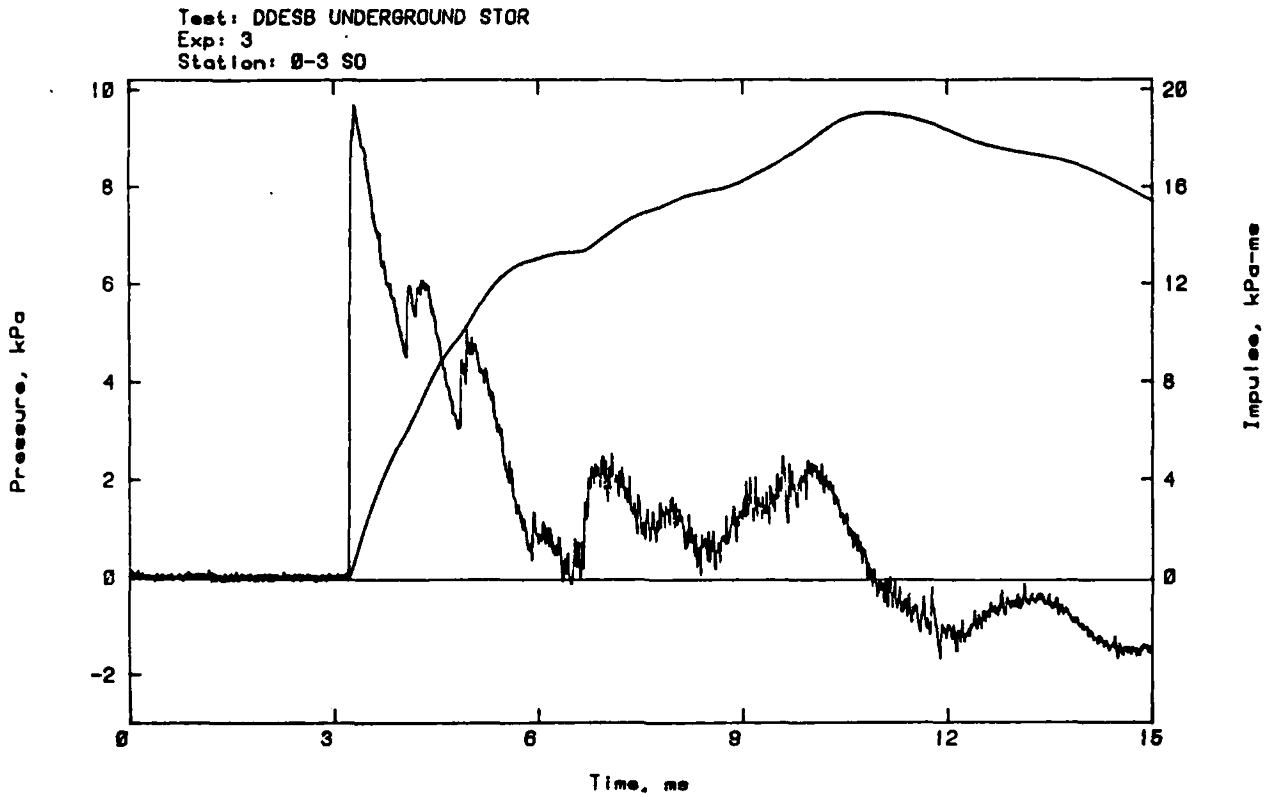


Figure A-3. Shot 3, chamber-loading density 1.46 kg/m^3, sand base.



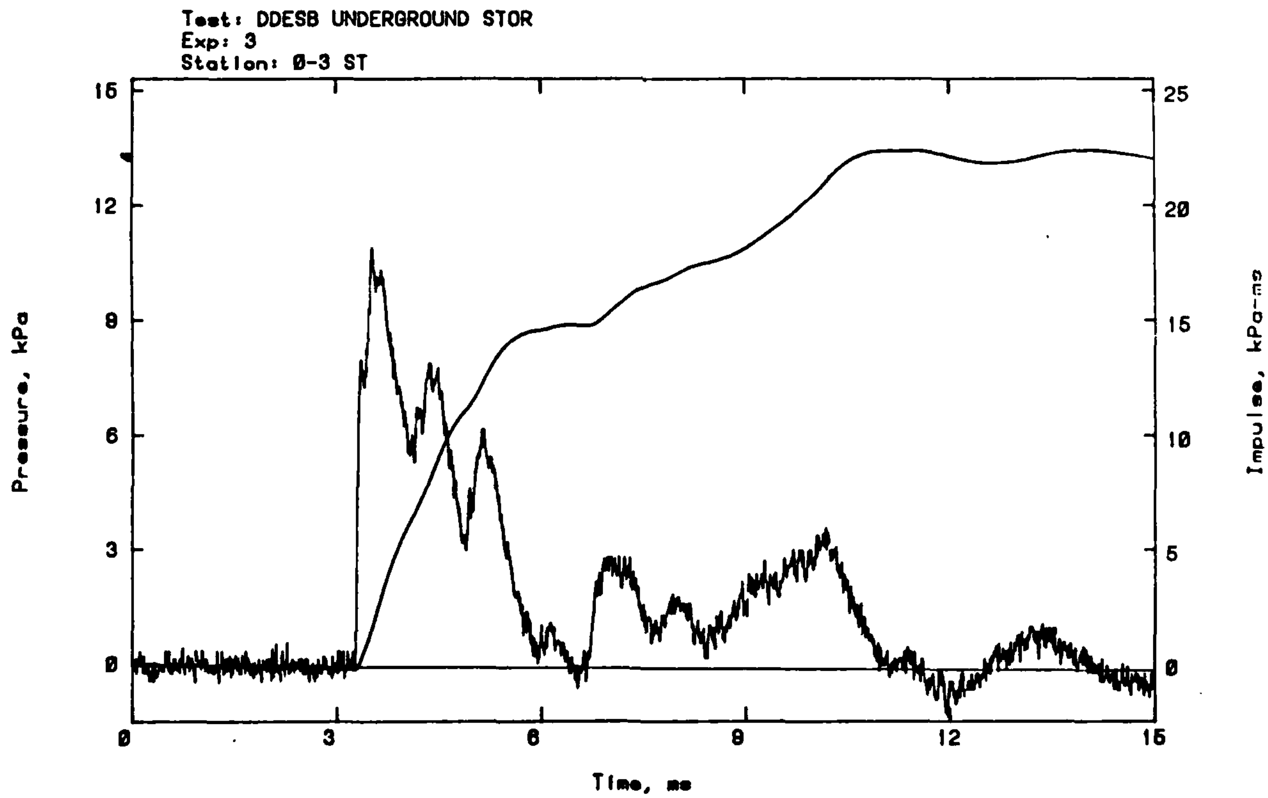


Figure A-3. Shot 3, chamber-loading density 1.46 kg/m^3, sand base.

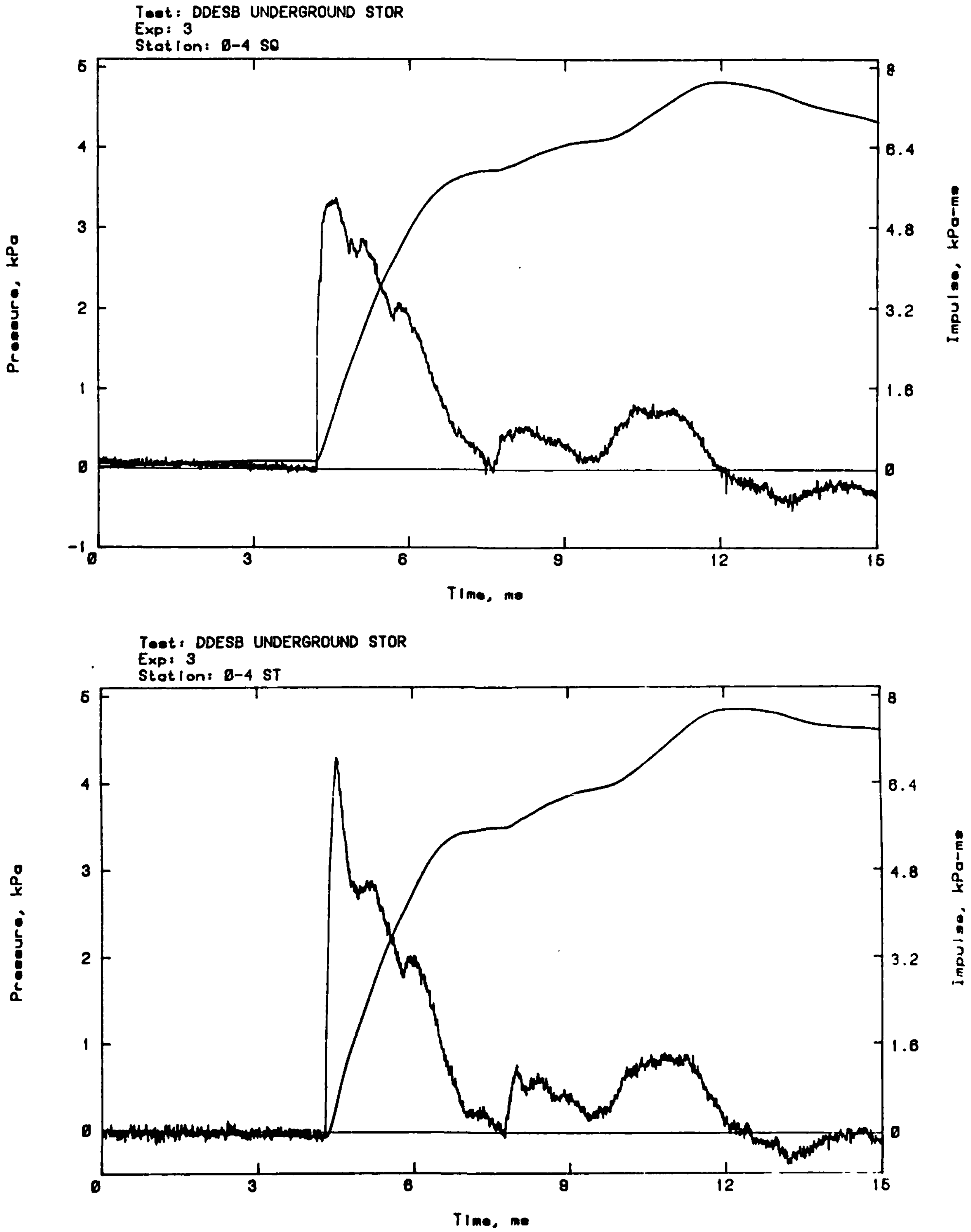
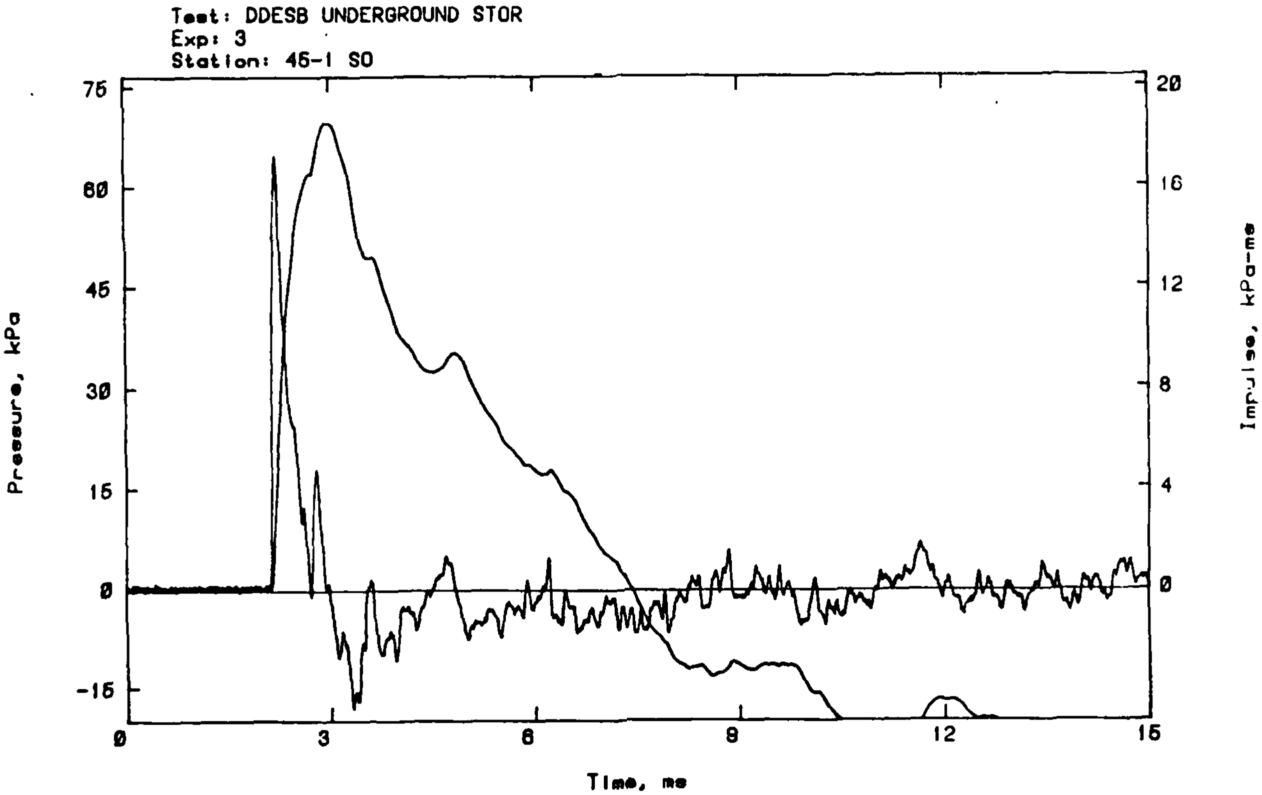


Figure A-3. Shot 3, chamber-loading density 1.46 kg/m^3, sand base.



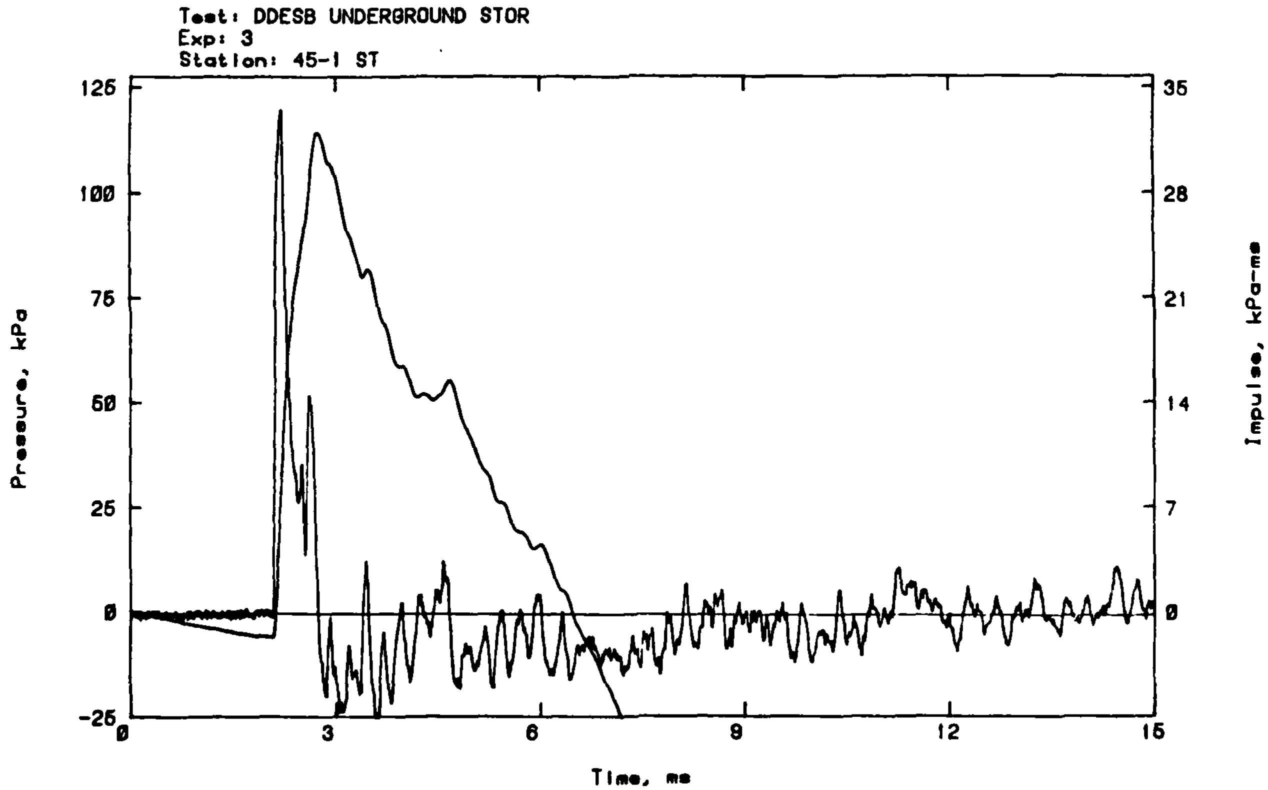
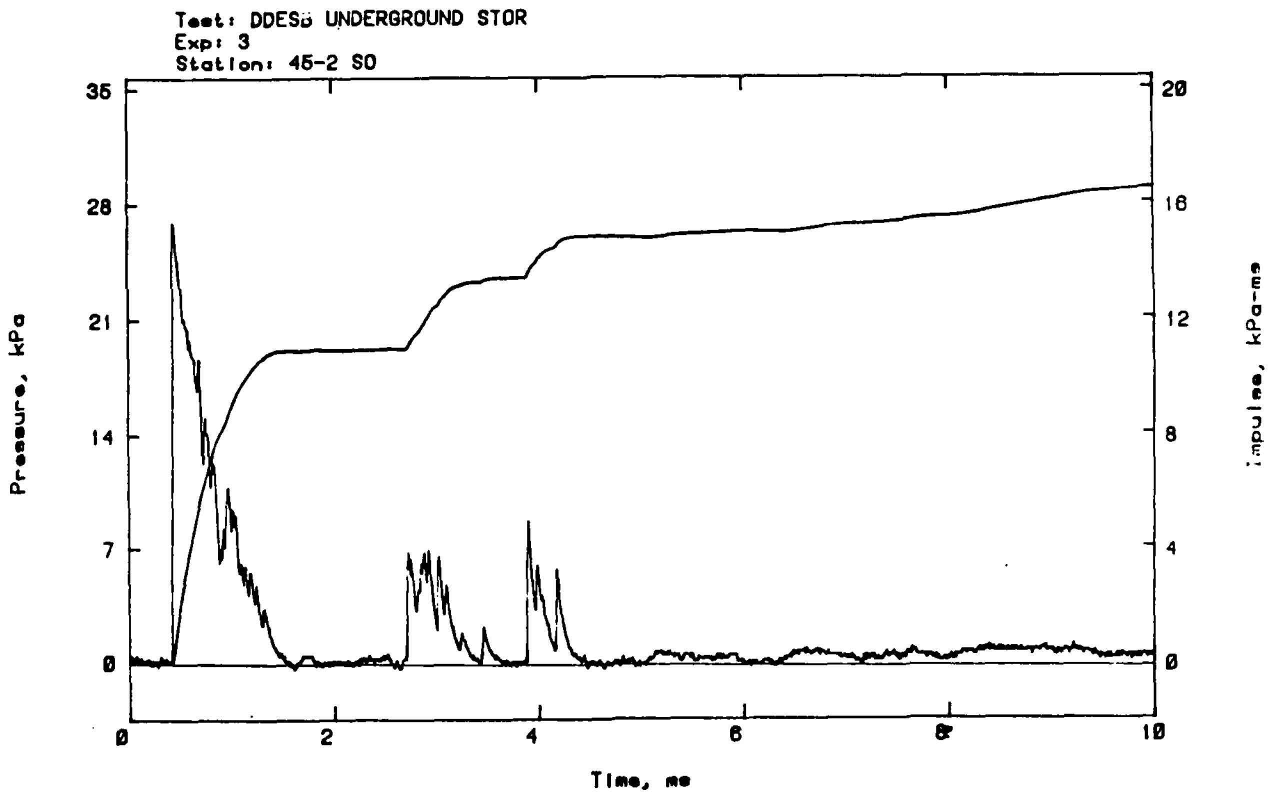


Figure A-3. Shot 3, chamber-loading density 1.46 kg/m^3, sand base.



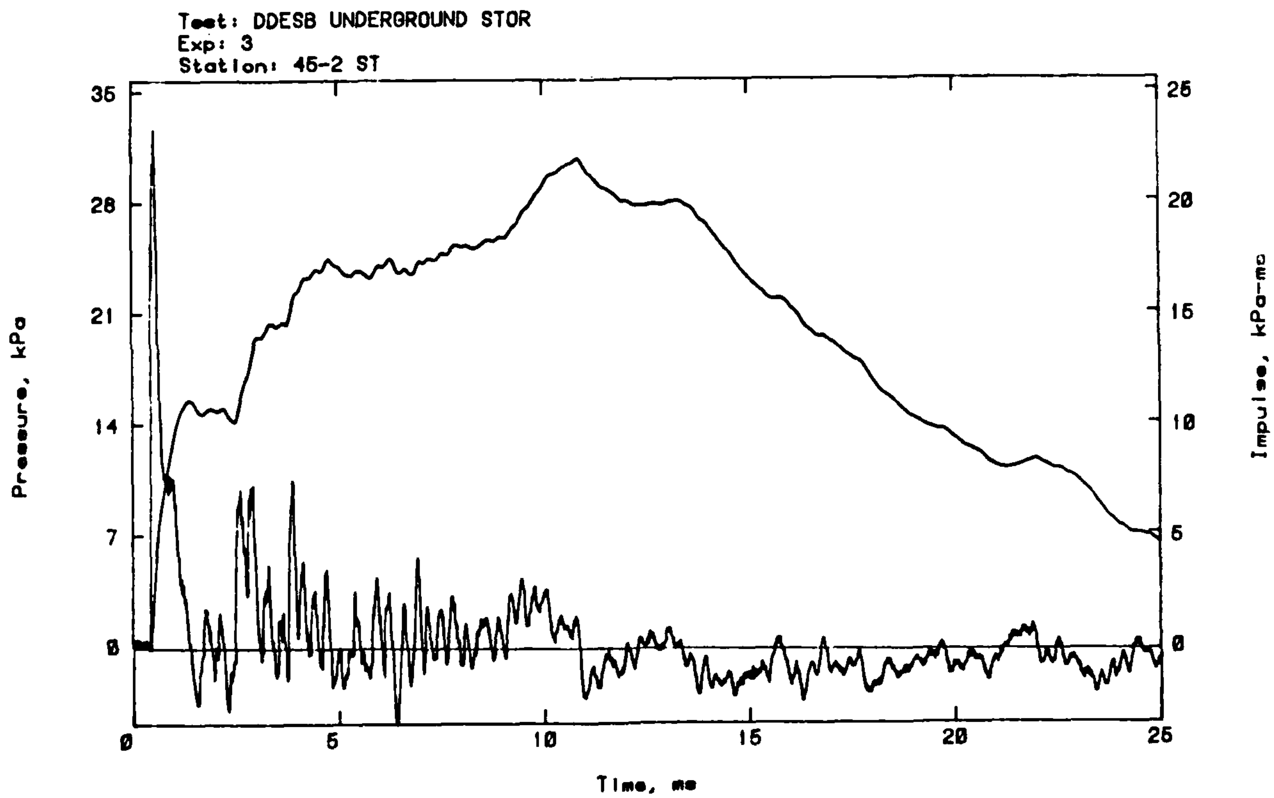
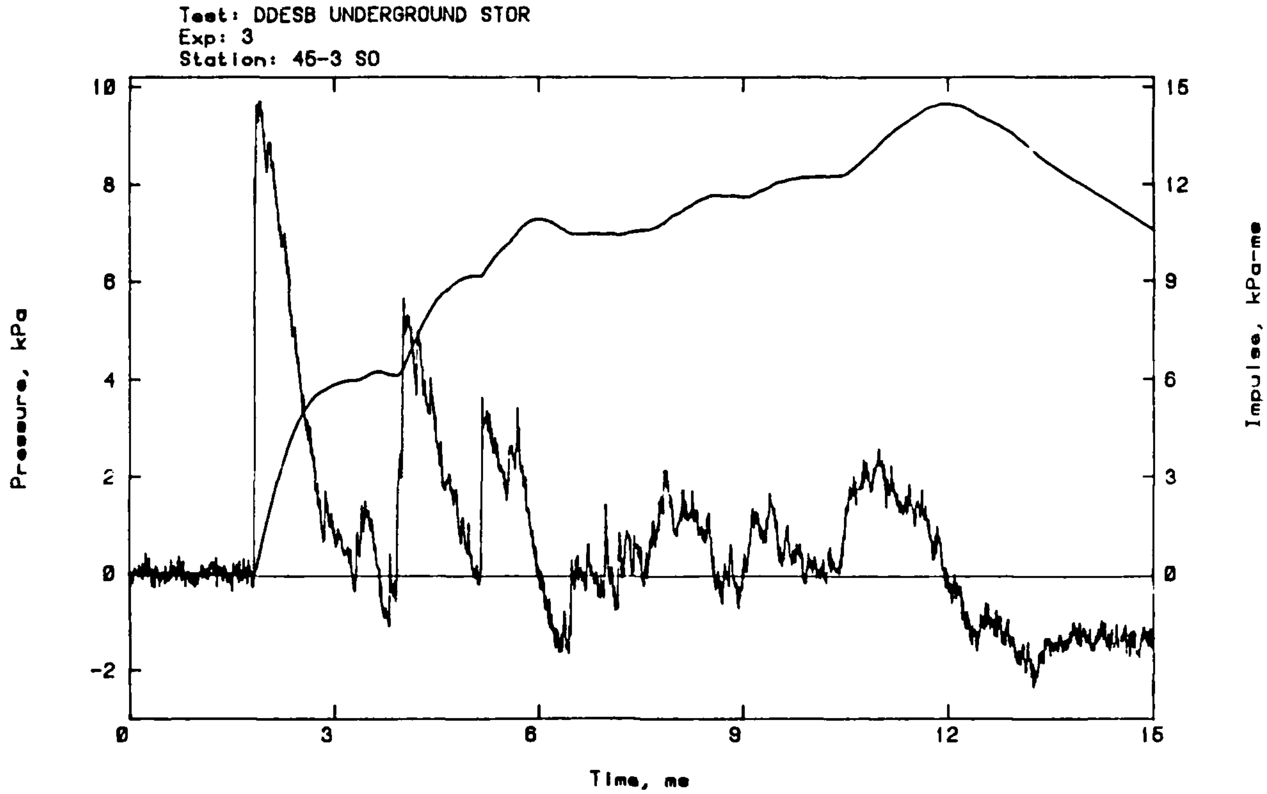


Figure A-3. Shot 3, chamber-loading density 1.46 kg/m^3, sand base.



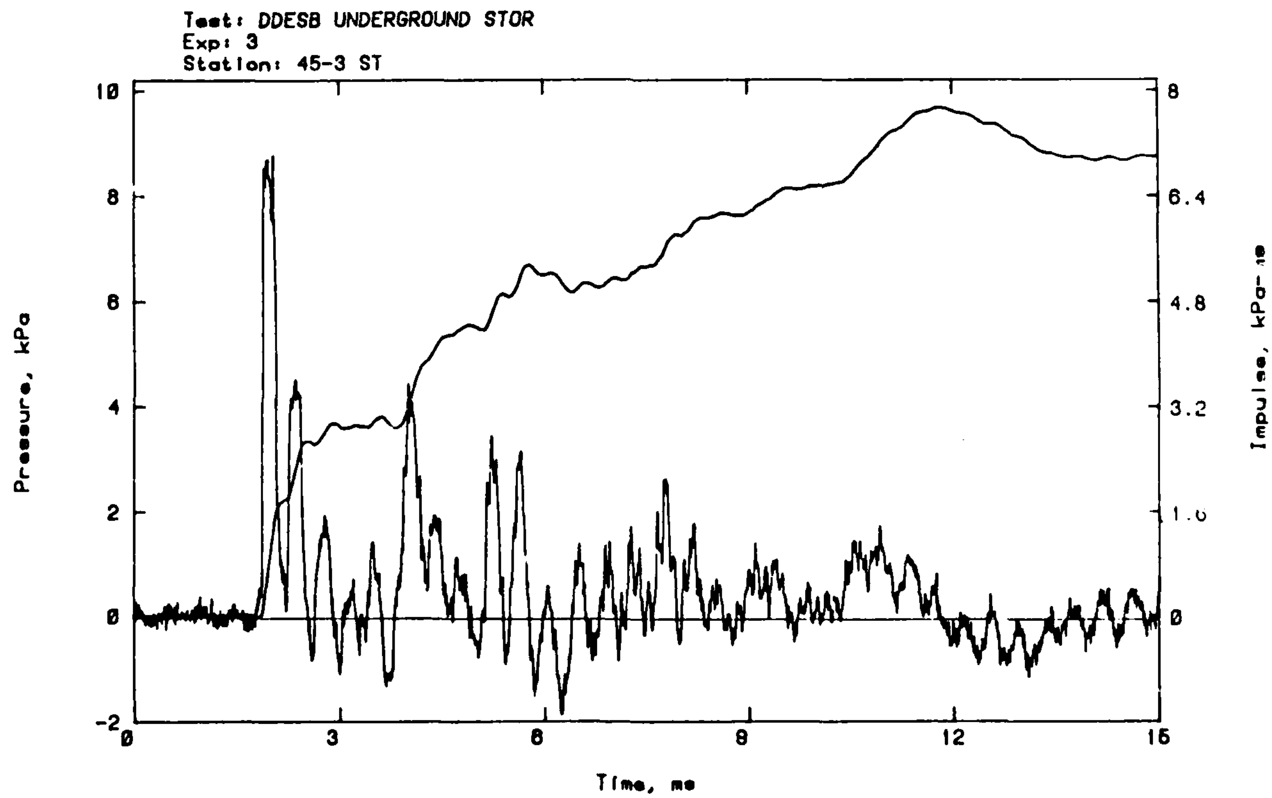
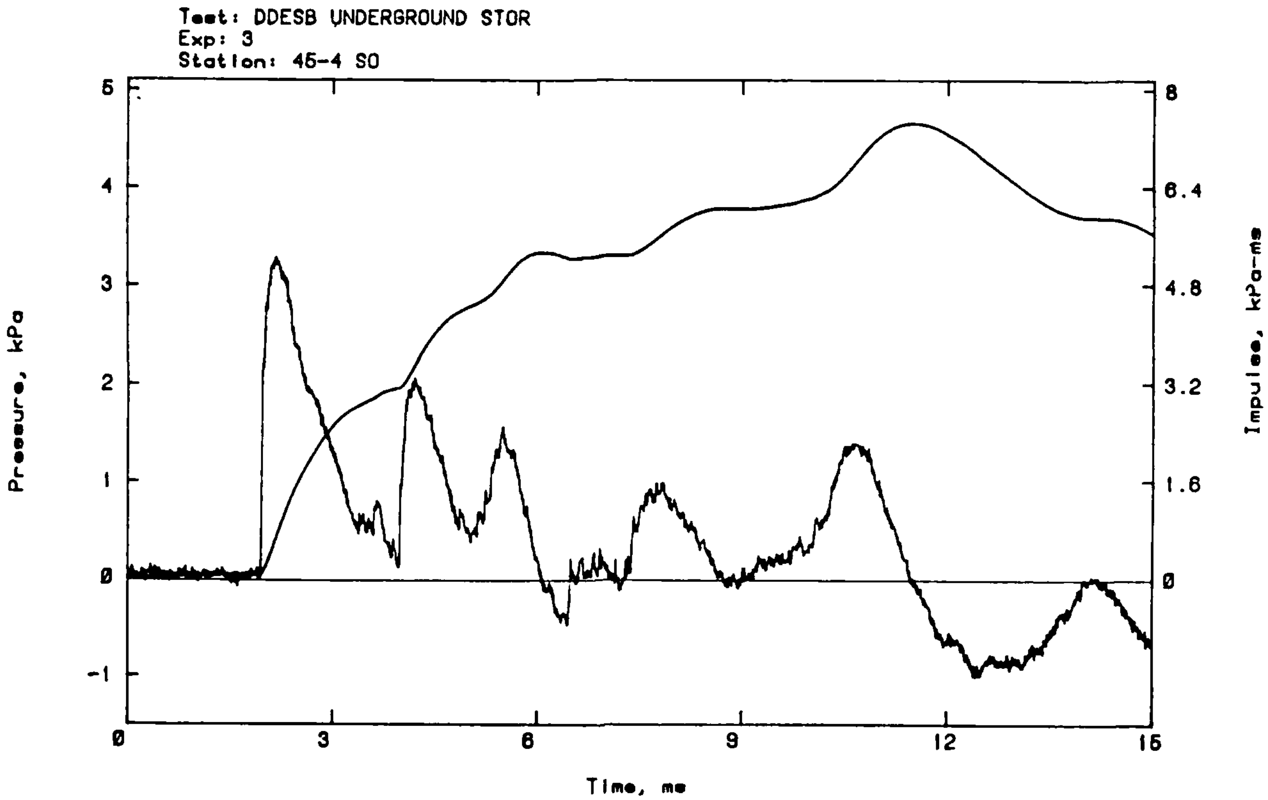


Figure A-3. Shot 3, chamber-loading density 1.46 kg/m^3, sand base.



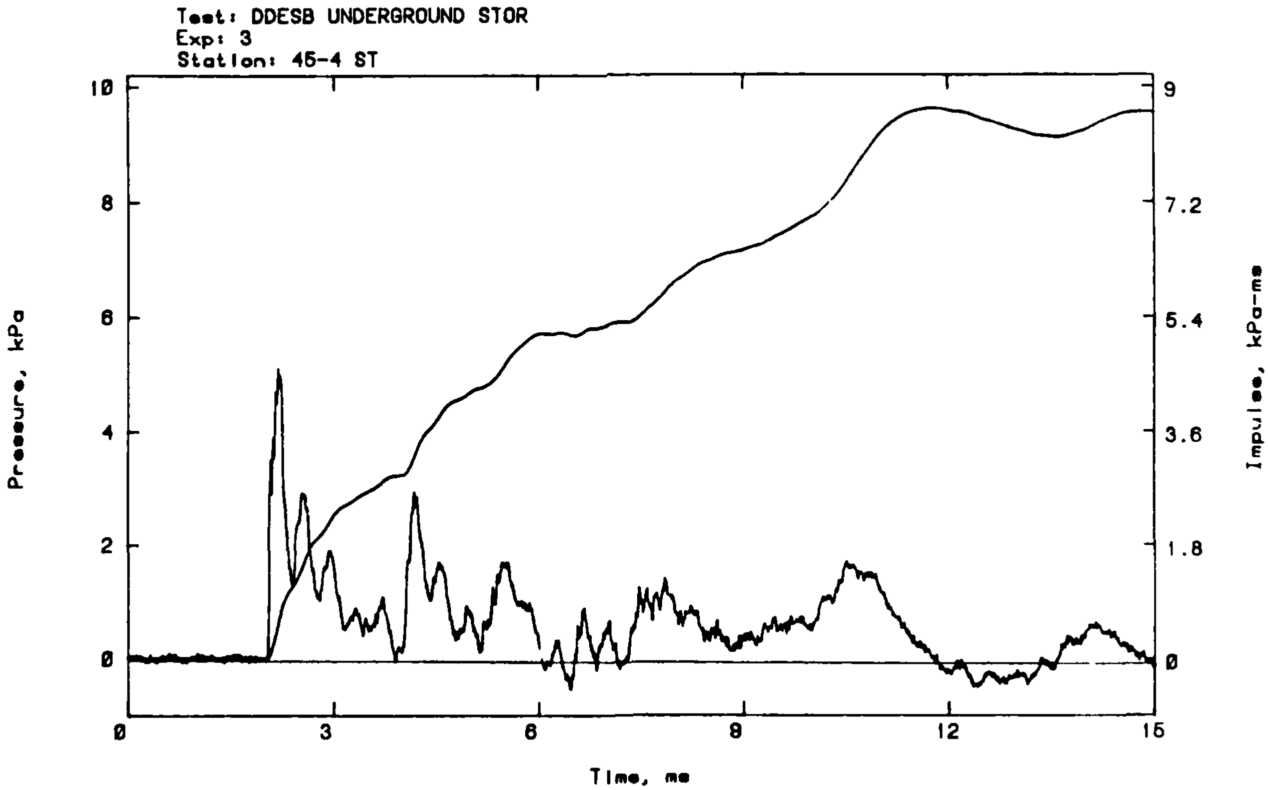


Figure A-3. Shot 3, chamber-loading density 1.46 kg/m^3, sand base.

STATION C-1 CURVE IS NOT AVAILABLE.

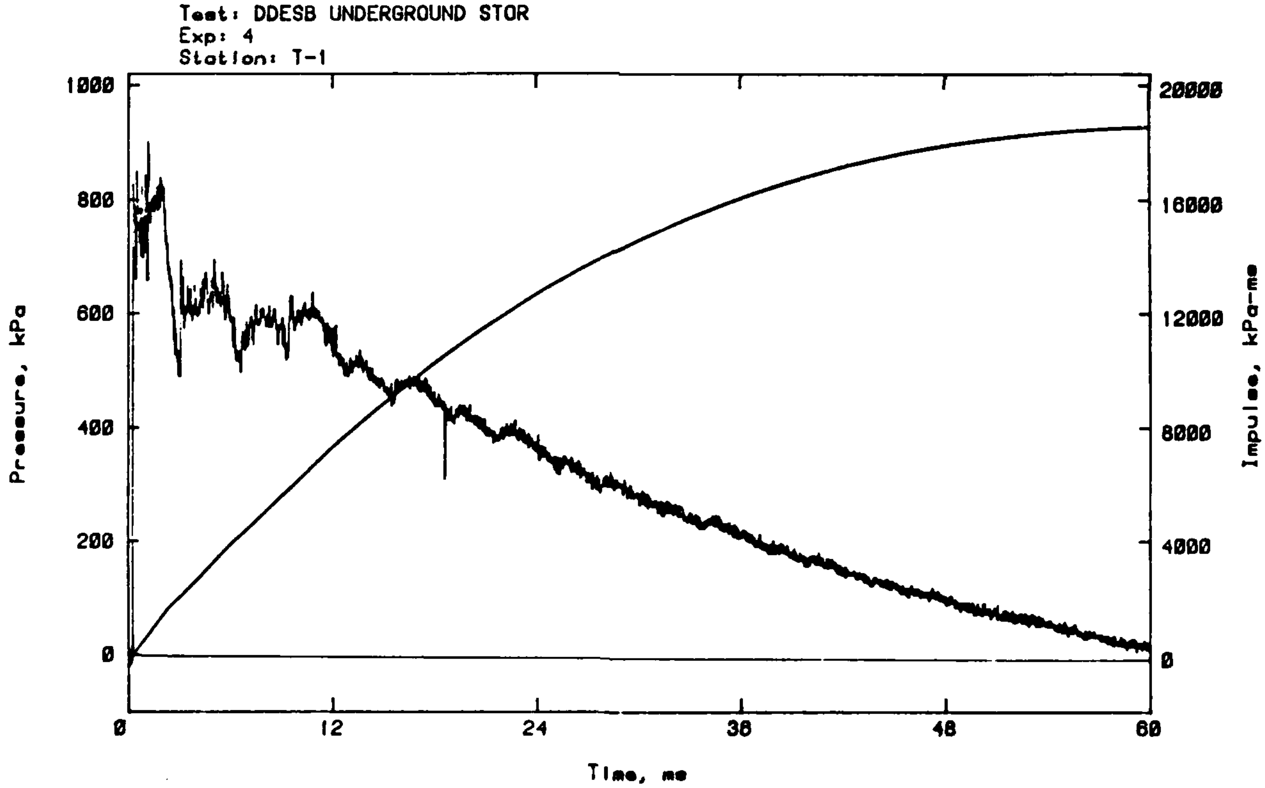
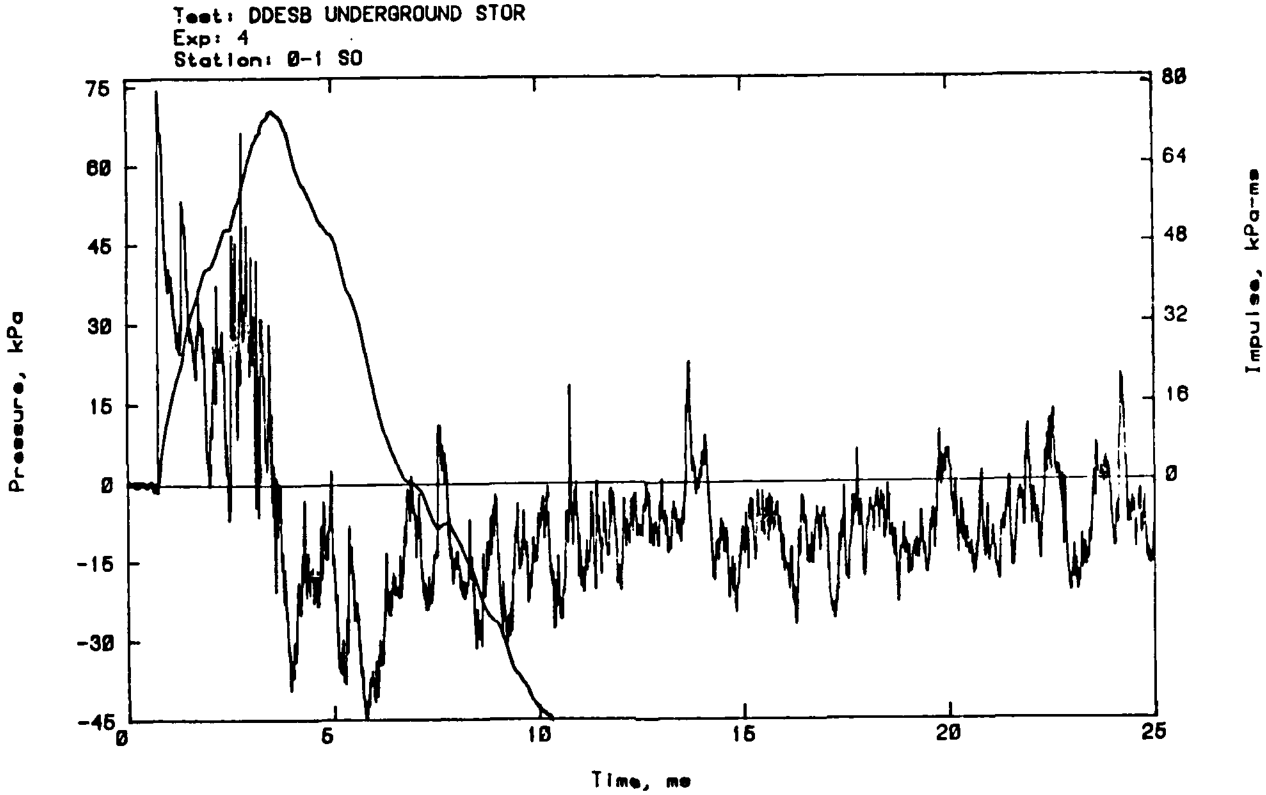


Figure A-4. Shot 4, chamber-loading density 1.46 kg/m^3, plywood base.



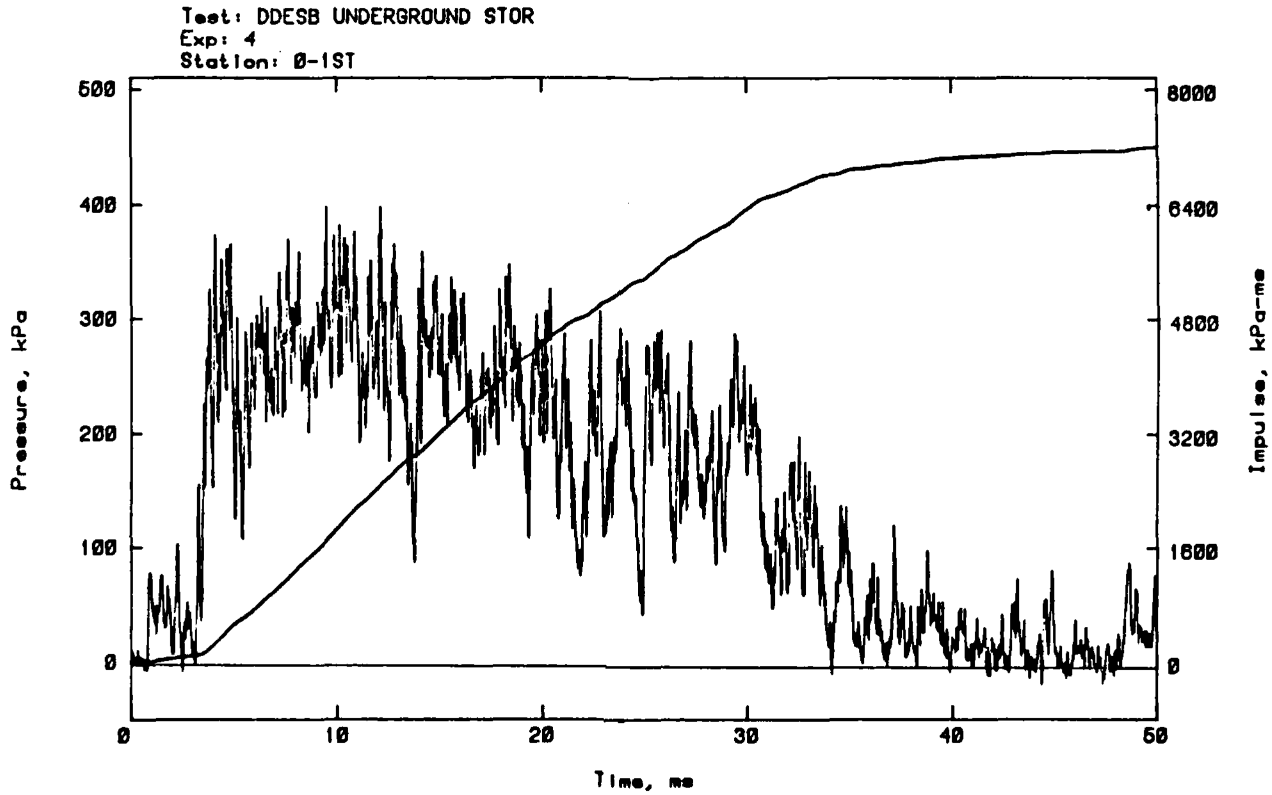
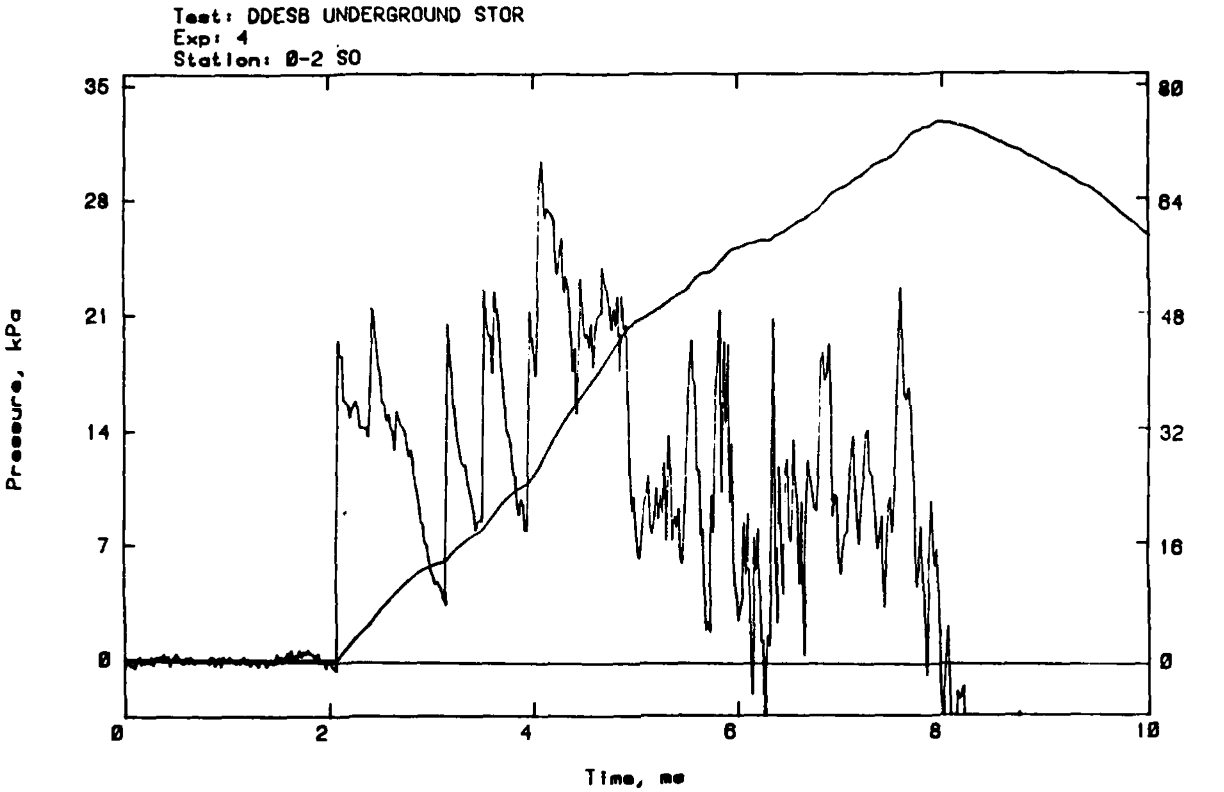


Figure A-4. Shot 4, chamber-loading density 1.46 kg/m^3, plywood base.



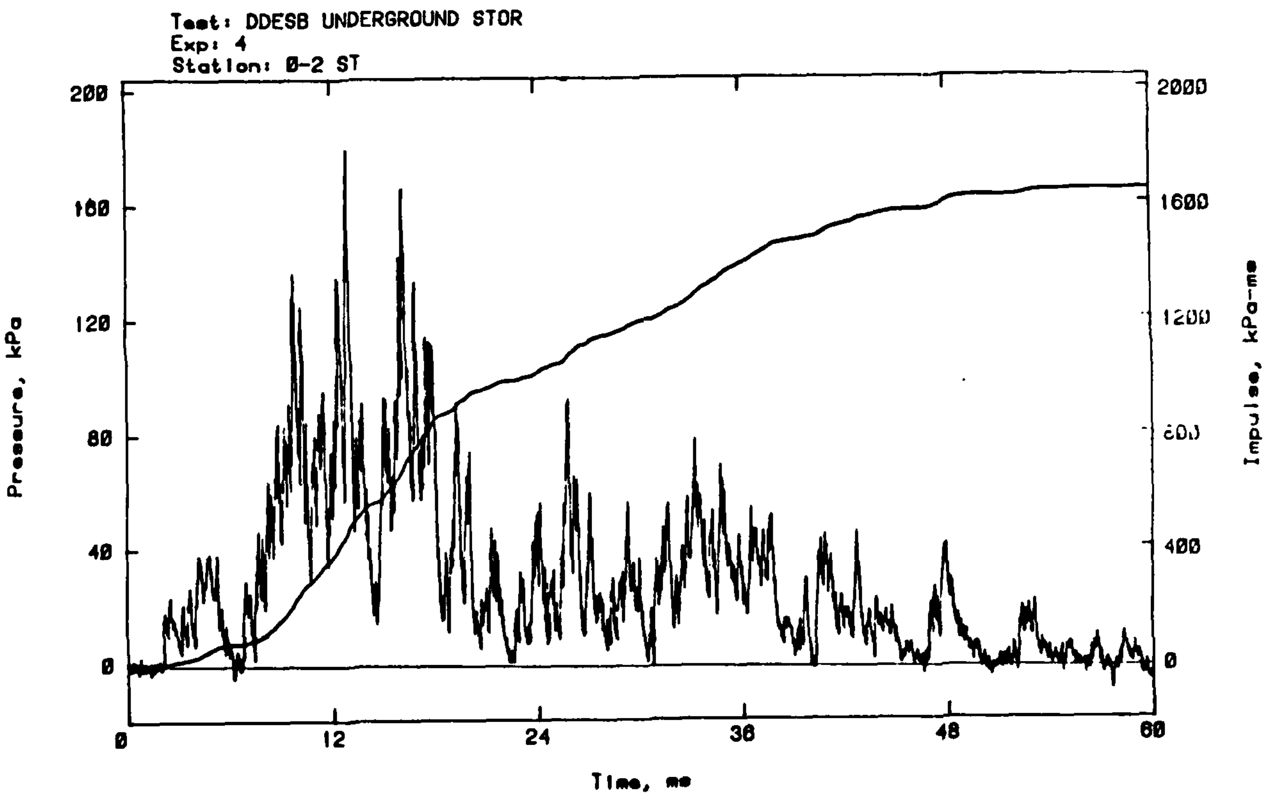
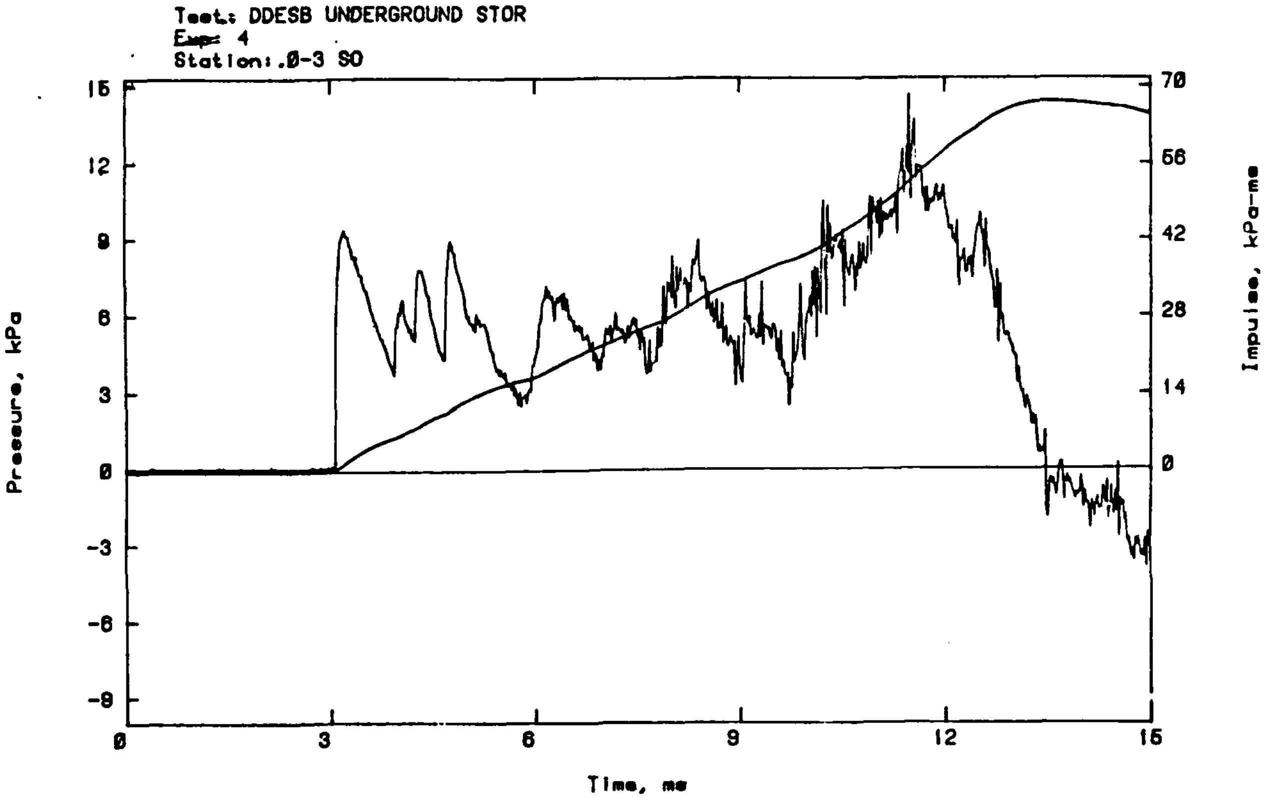


Figure A-4. Shot 4, chamber-loading density 1.46 kg/m^3, plywood base.



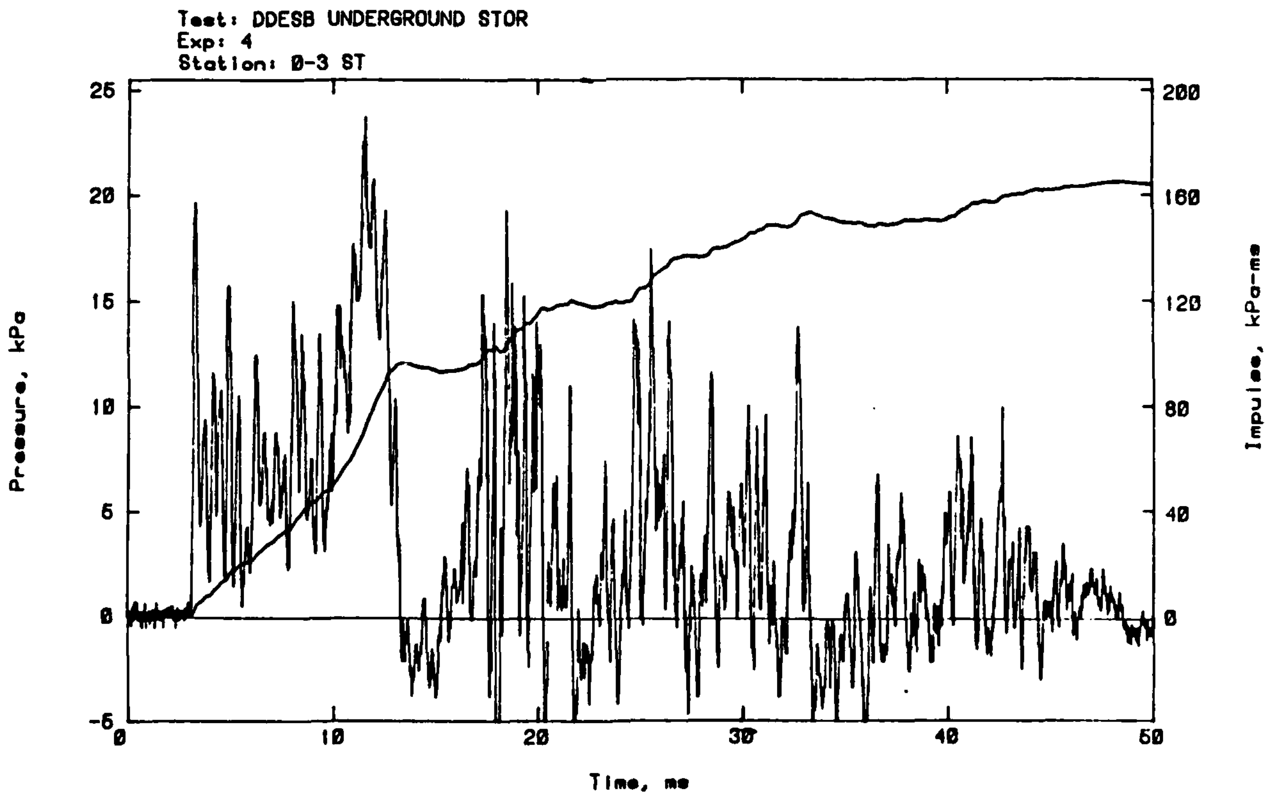
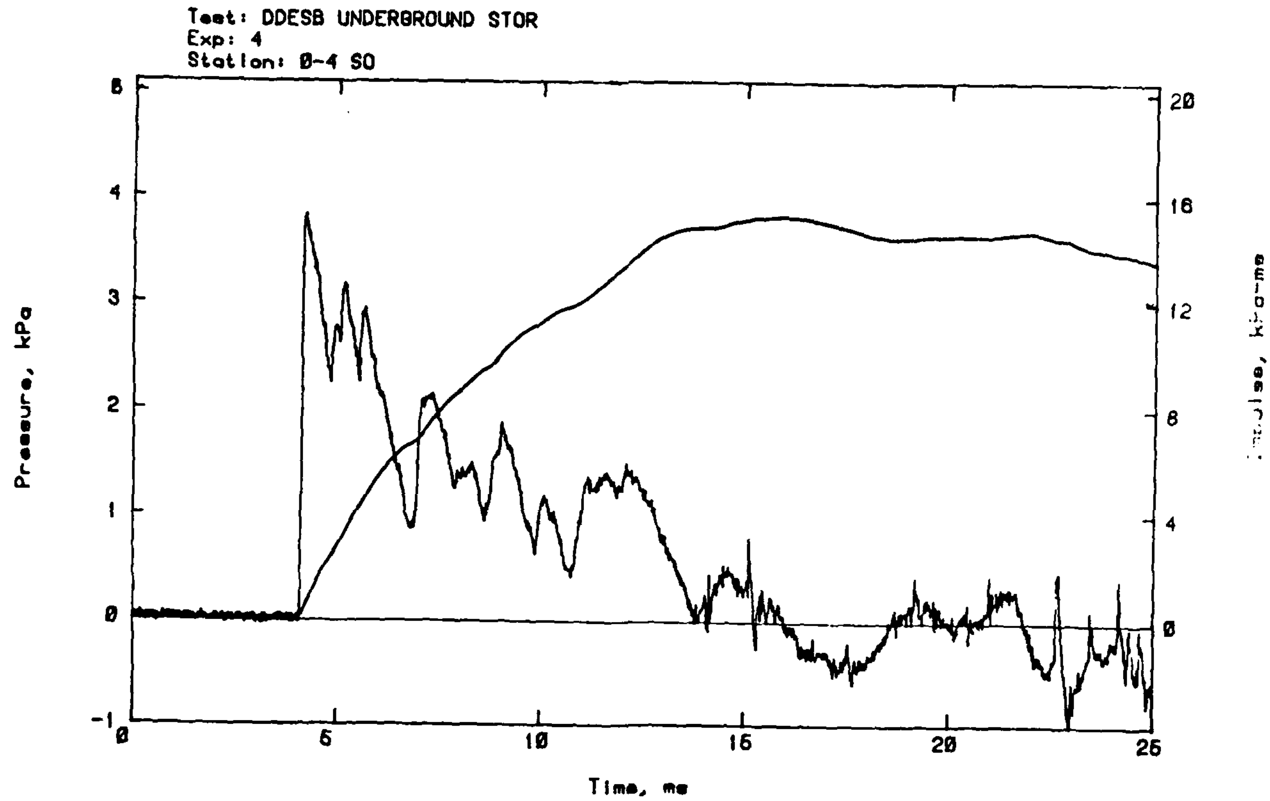


Figure A-4. Shot 4, chamber-loading density 1.46 kg/m³, plywood base.



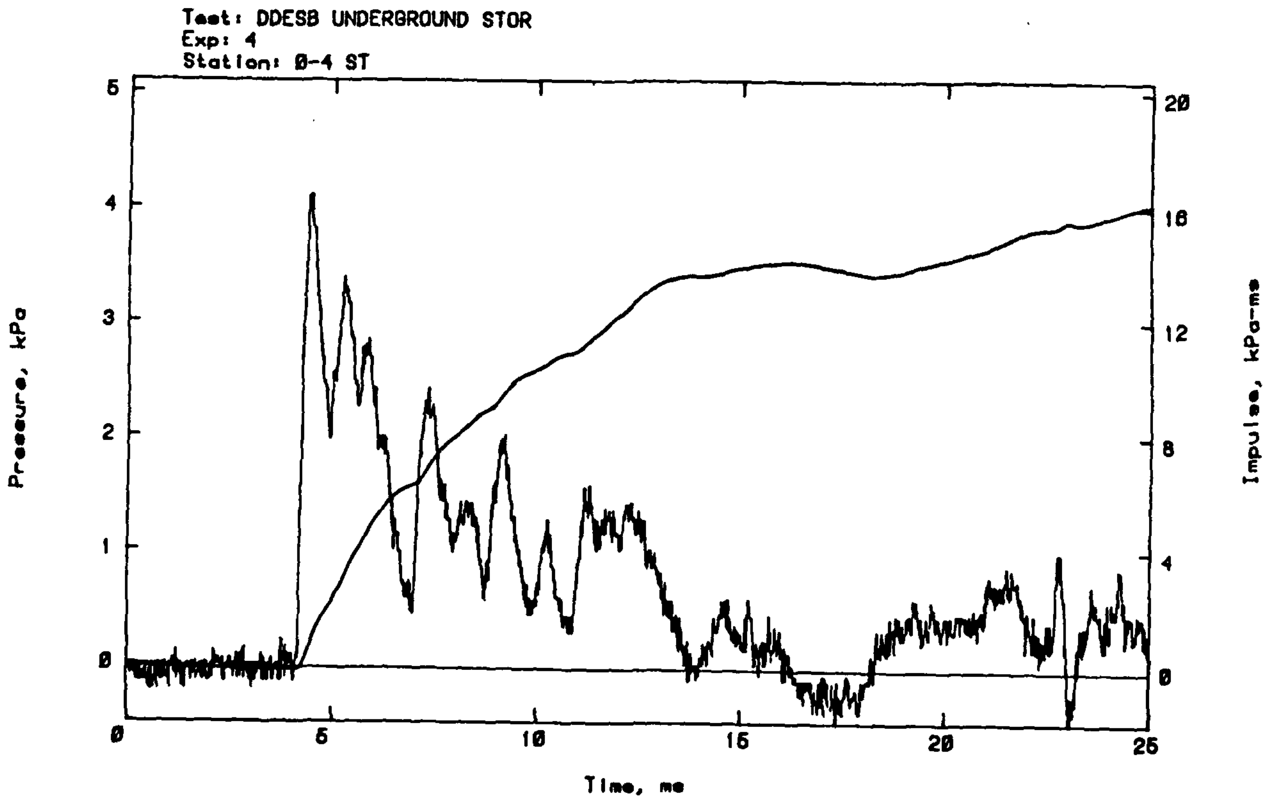


Figure A-4. Shot 4, chamber-loading density 1.46 kg/m³, plywood base.

STATION C-1 CURVE IS NOT AVAILABLE.

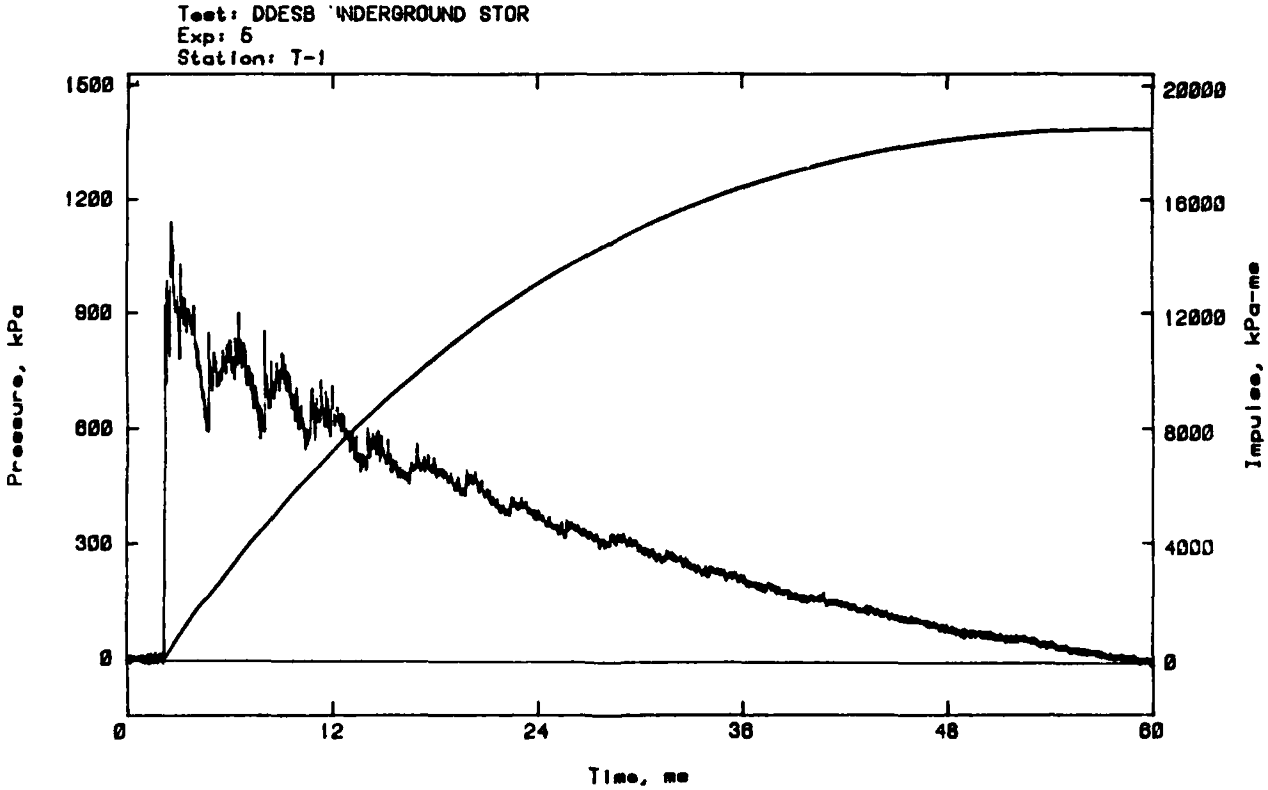
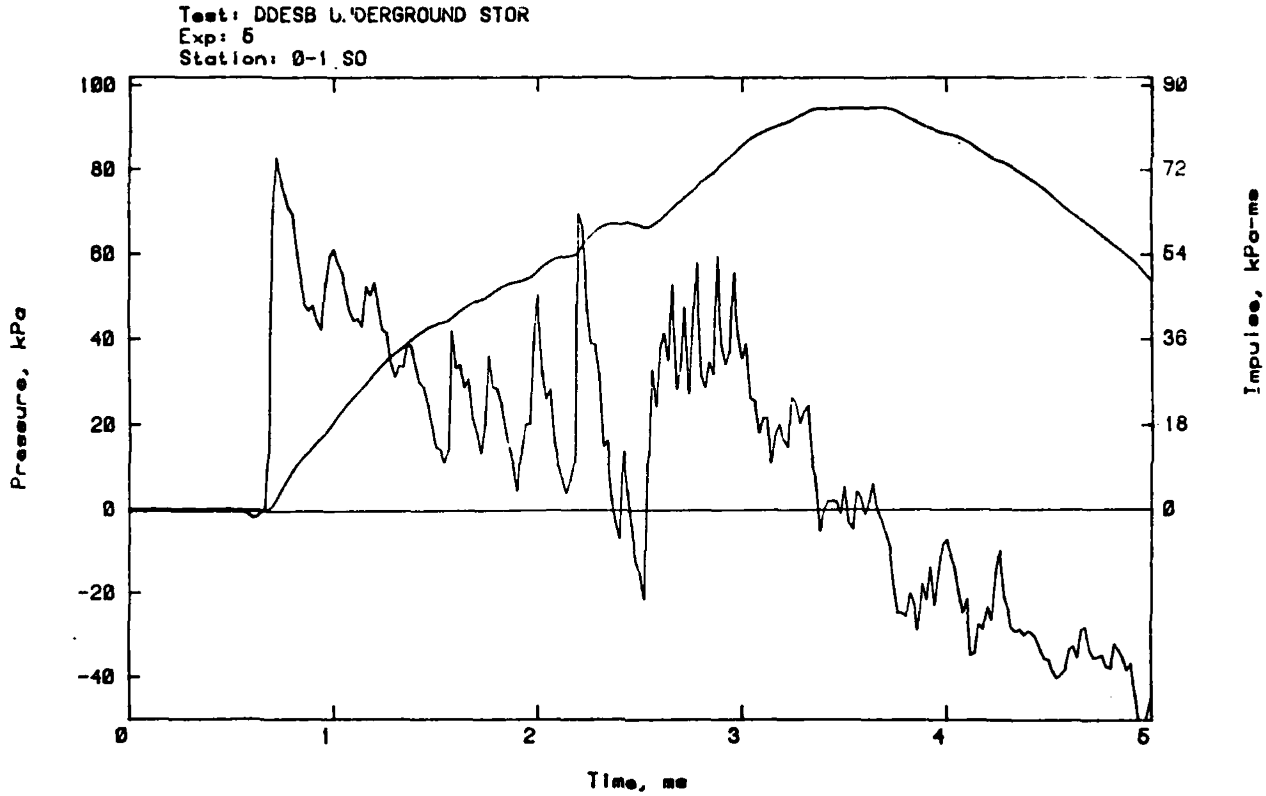


Figure A-5. Shot 5, chamber-loading density 1.46 kg/m^3, plywood base.



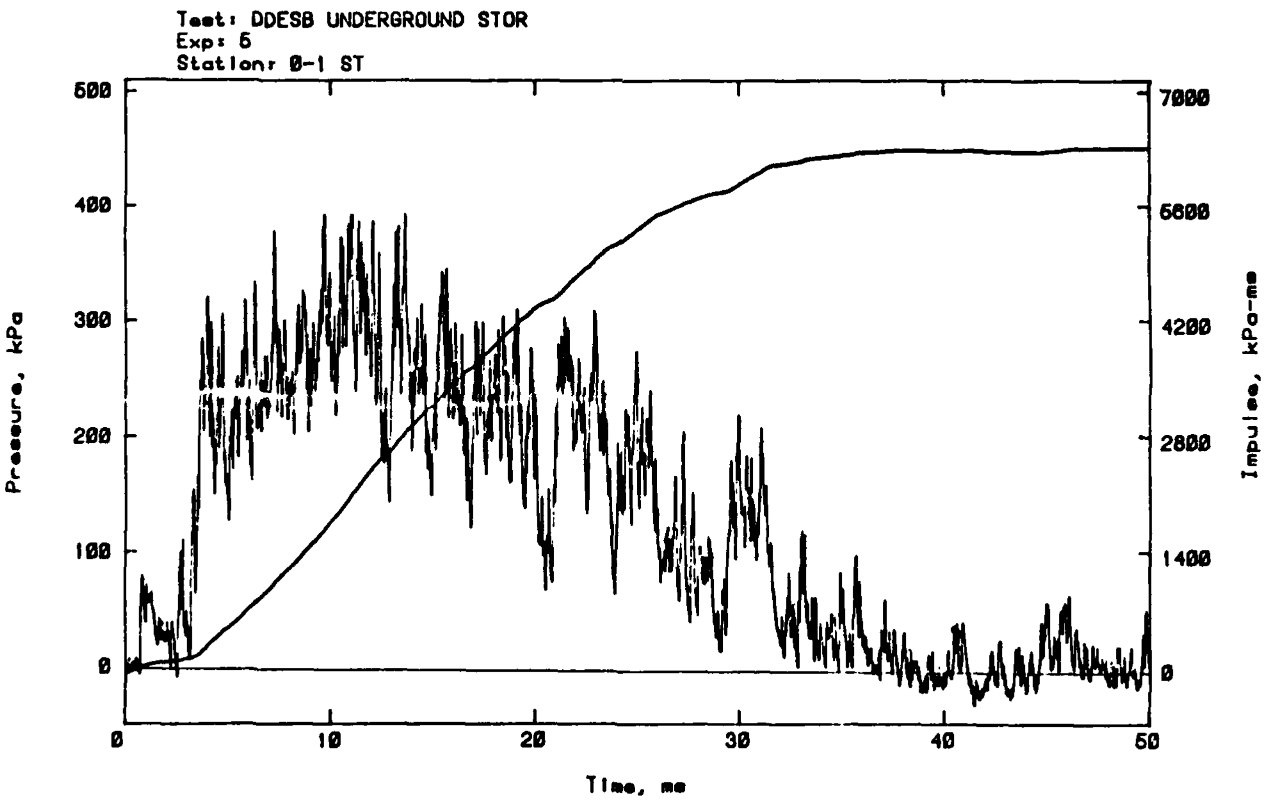
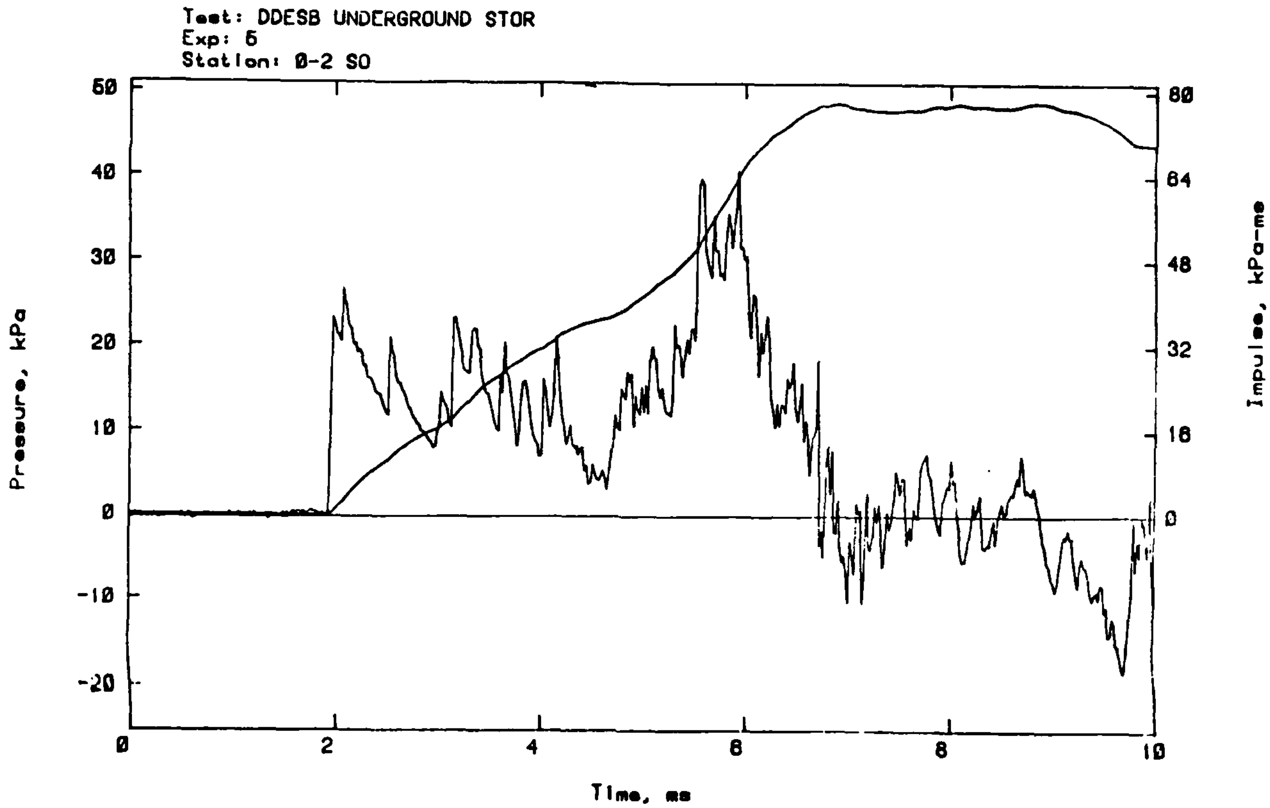


Figure A-5. Shot 5, chamber-loading density 1.46 kg/m^3, plywood base.



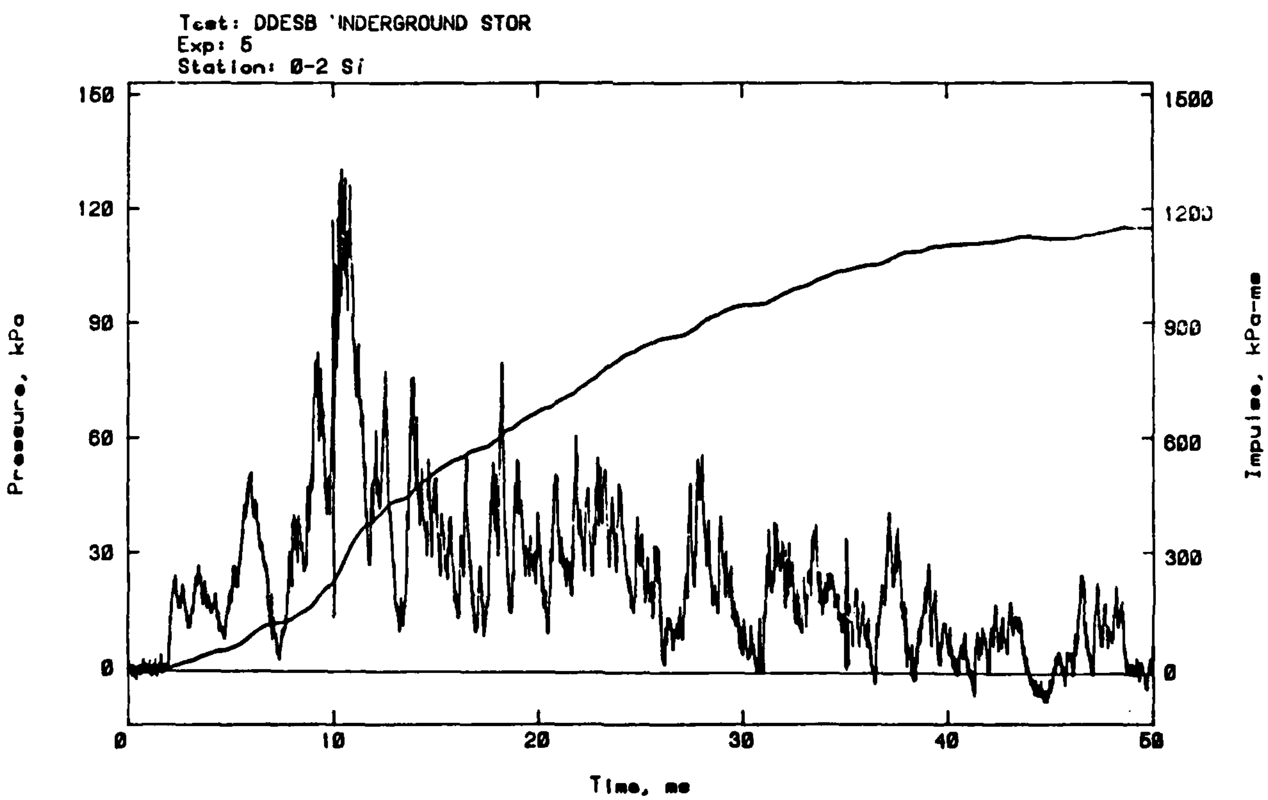
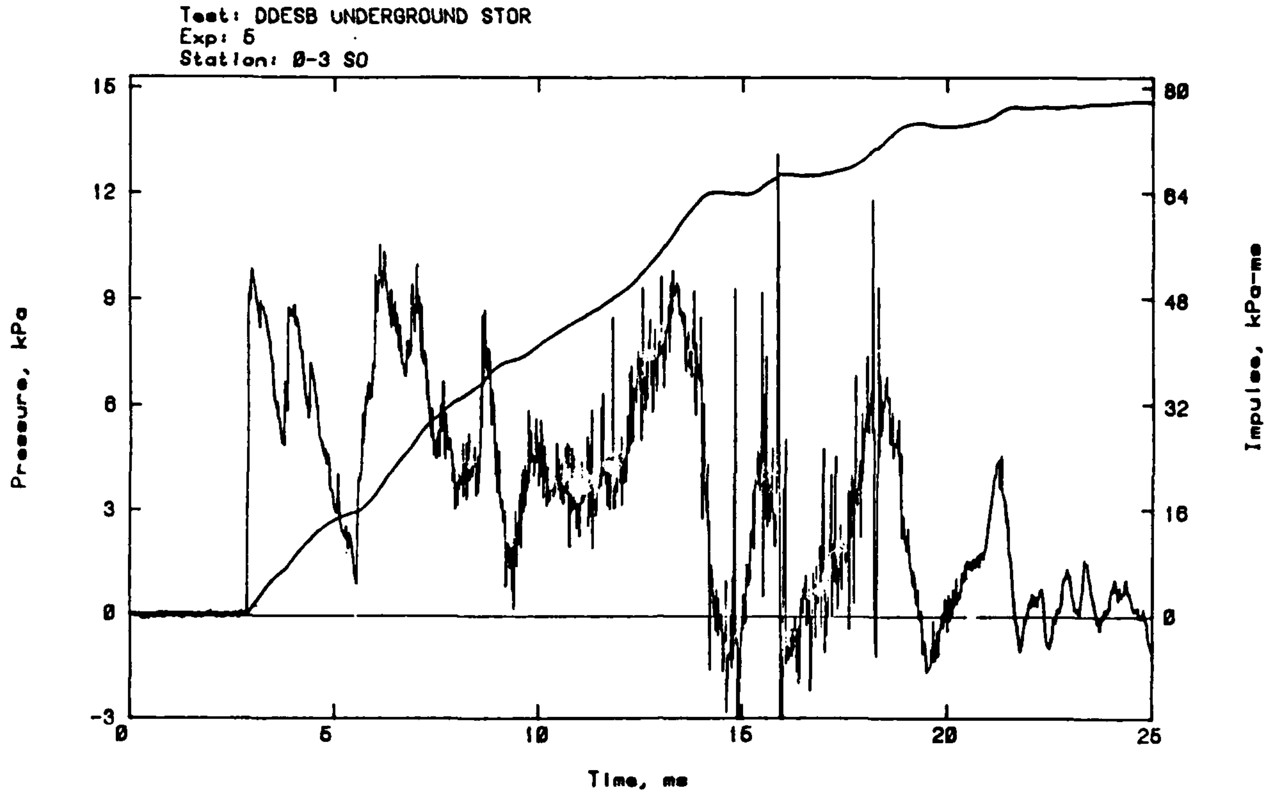


Figure A-5. Shot 5, chamber-loading density 1.46 kg/m^3, plywood base.



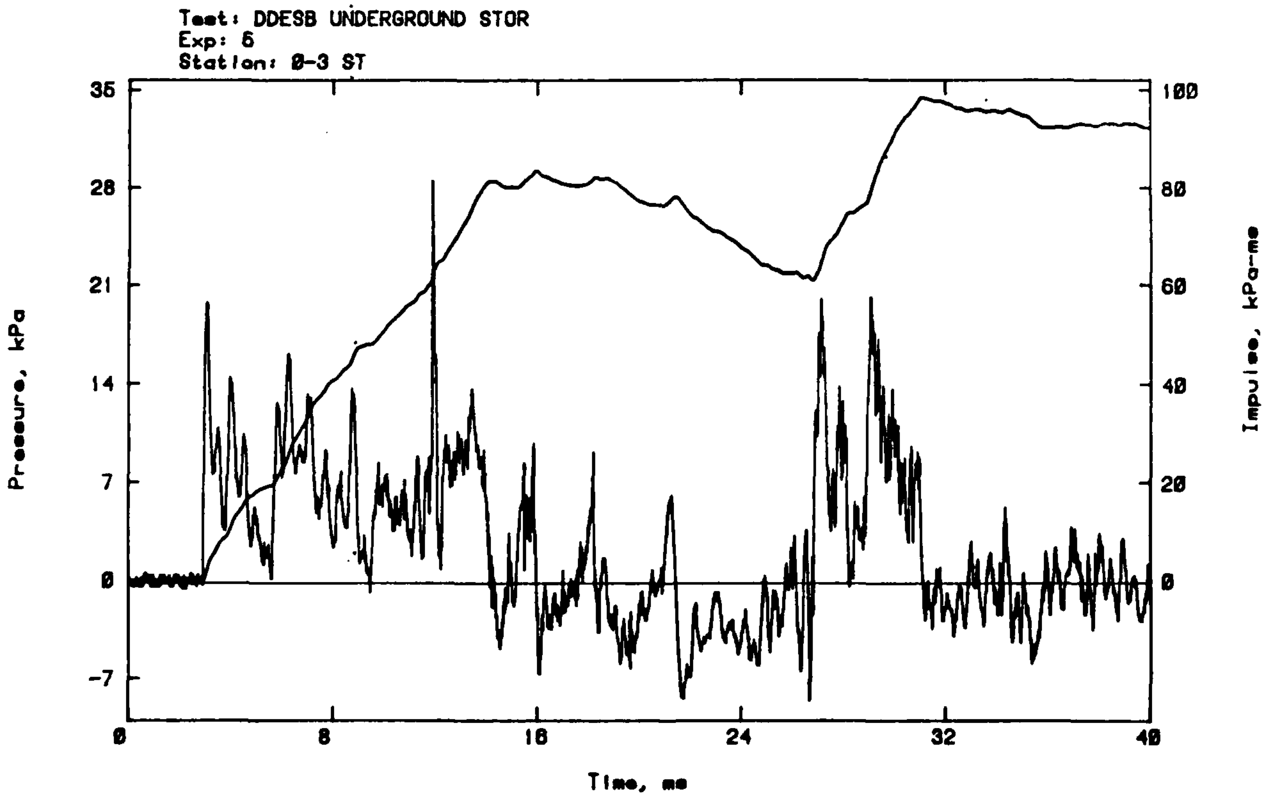
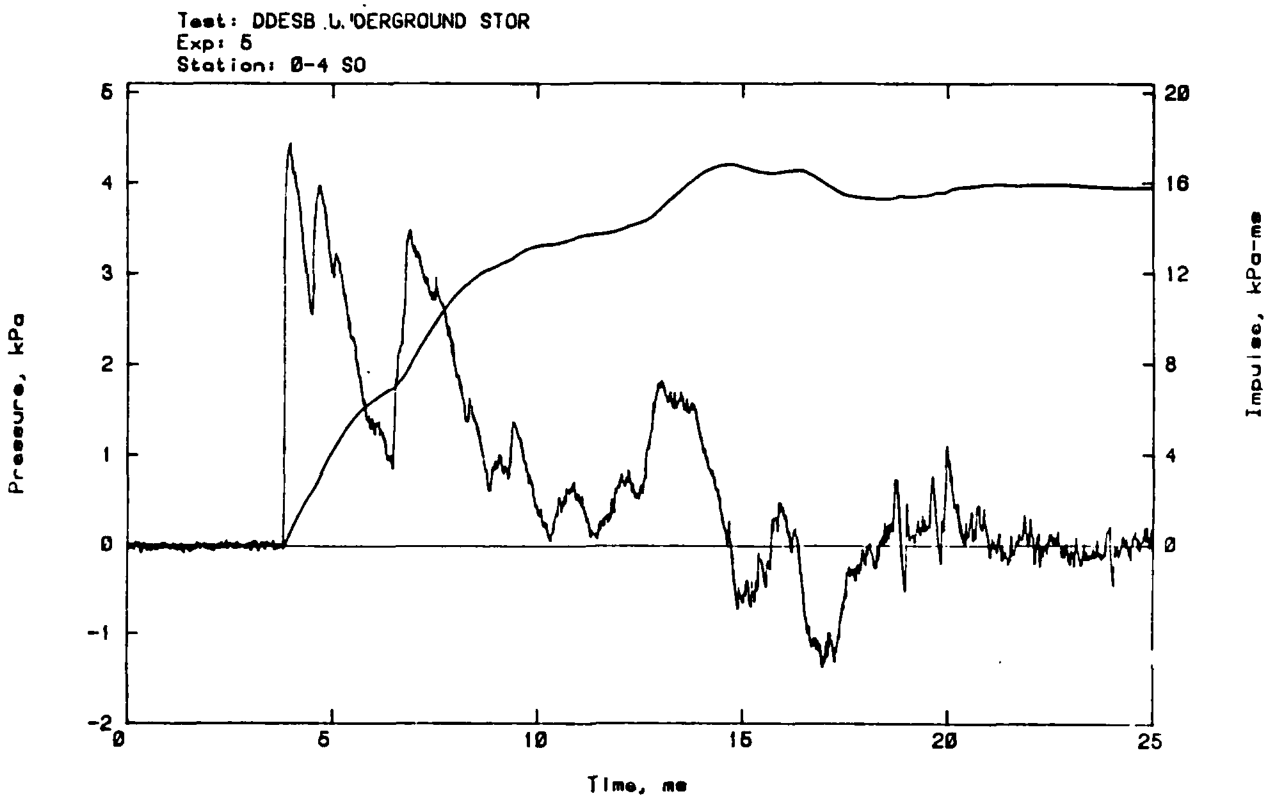


Figure A-5. Shot 5, chamber-loading density 1.46 kg/m^3, plywood base.



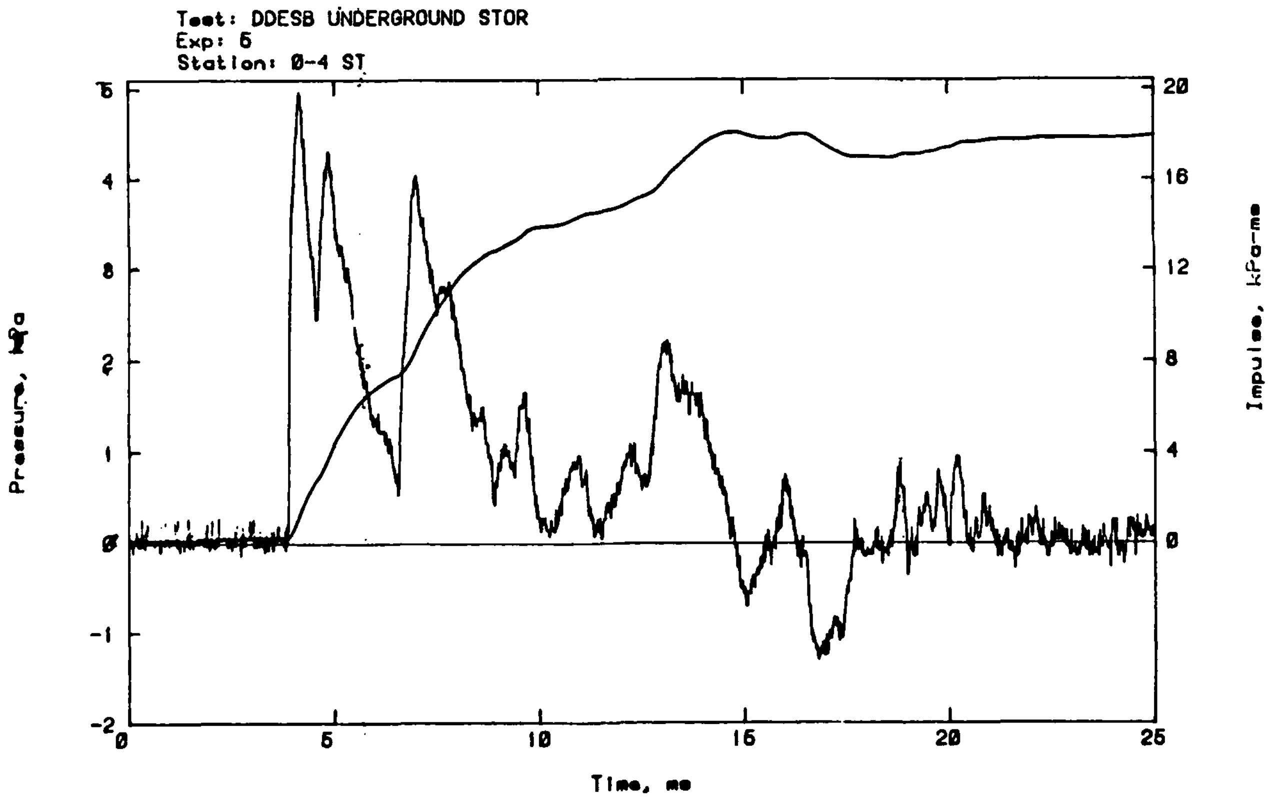


Figure A-5. Shot 5, chamber-loading density 1.46 kg/m³, plywood base.

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